Simulation of the Beam Delivery System, Interaction Region and Backgrounds using BDSIM

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BDSIM is a GEANT4-based simulation tool designed for the easy modelling of accelerator beam-lines. Fast accelerator-style particle tracking through accelerator components is combined with traditional Runge-Kutta tracking techniques to provide an efficient system for simulation of background and secondary effects both along the beam-line and in the detector region. The code is described and some preliminary background simulations reported.

1. INTRODUCTION

`BDSIM` is a Geant4 [1] based code for simulating accelerator beam-lines, which combines fast accelerator-style tracking with the traditional tracking techniques of particle-phyiscs. The first version of `BDSIM` [2] dates back several years and has evolved since then to include improved interfacing to standard accelerator descriptions, improved particle interactions including interface to the Geant4 hadronic packages, and an ongoing project to improve the interface to complex field maps such as are needed for detailed descriptions of detector and accelerator magnetic fields. The `BDSIM` code uses Geant4 to build the individual beam-line elements including drifts, sector bends, quadrupoles, sextupoles, octupoles and decapoles. Adopting an object oriented approach, each beam-line element is constructed as a separate object with its own outer geometry, beampipe and magnetic fields. The early input to the program was in the form of a MAD [3] optics file, but this has been updated recently to allow input by the MAD deck directly, supplemented with descriptions of geometries, materials and field maps.

2. BDSIM TRACKING

Inside the beampipe a new approach is adopted. Rather than track the particles using a locally-defined magnetic field strength, the approach more commonly adopted by accelerator tracking codes is followed, using an analytic solution to the equations of motion. For example, the track of a particle moving in a uniform magnetic field describes a circle, so the solution to the equation of motion is known and does not need to be solved locally. Similarly a particle moving in an idealised quadrupole field has equations of motion with an analytic solution. By using the analytic solutions directly, a significant time saving is obtained over the more usual Geant approach of solving locally for a step in a magnetic field. Of course, this is only useful when the magnetic fields have a simple form. For more complex fields a full field map will be required; this functionality is also included in the latest version of `BDSIM`. For higher order multipoles such as sextupoles, octuples, or decapoles, a simpler approach is adopted where the particles receive a momentum kick dependent on their position on entering the multipole. This approach, also common in accelerator physics, works well enough for the purpose of tracking through the beam delivery system; although detailed field maps may be needed at some locations in the post-interaction point (IP) extraction line.

The implementation of this accelerator style tracking is performed through the use of dedicated "steppers". In practice this is effected by assigning each "logical volume" its own stepper so that when a particle enters that volume it automatically picks up the stepper of that volume, which in turn determines how the particle is transported. Given a particle of energy E and input transverse position x, y with respect to the longitudinal position along the beampipe, z, and angles x', y' with respect to the distance travelled (Δs) the final co-ordinates can be determined directly within the stepper. The magnitude of the step length Δs is provided by the Geant4 code and depends

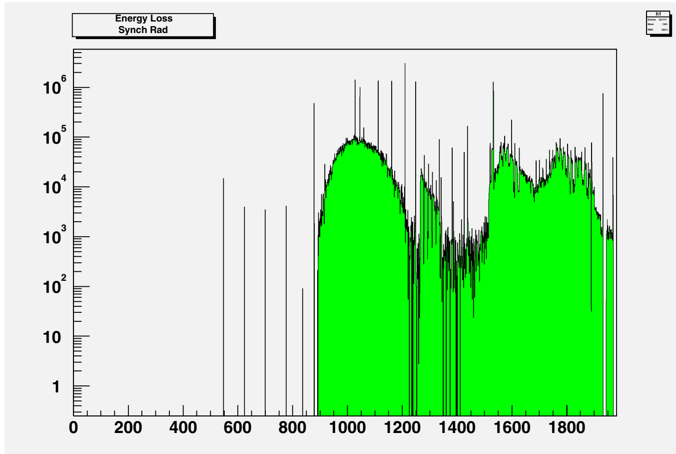

Figure 1: Deposition of SR along the beam-line in GeV/m for the ILC beam delivery system. The linac exit is at $z = 0$.

on which processes are present. For most cases, the step length is equal to the length of the beam-line element because the particles are travelling in high vacuum. However, for studies with finite pressure or with the inclusion of synchrotron radiation (SR), the step length will vary from step to step, with distributions given by the mean free path of the process involved. Scattered particles, or those halo particles in outer positions of phase-space, can leave the beampipe. Once outside the beampipe, tracking defaults to the usual Geant4 approach where steps are calculated from local fields (if present) using Runge-Kutta techniques and material interactions are included in full. The accelerator-style tracking performance has been tested in detail as part of a comparison of a wider set of tracking codes [4], where good agreement with other accelerator trackers was found.

3. BDSIM PROCESSES

`BDSIM` has easy access to all the impressive range of processes included in Geant4. These processes include multiple scattering off beam-gas particles or in detector elements and the usual electromagnetic shower processes such as electron-positron pair creation and bremsstrahlung. The beam-gas is specified by a normal Geant4 material with a pressure that can be defined by the user. Neutron generation from photo-production can also be included using the Geant4 nuclear processes [5].

SR can also be included so that generation of synchrotron photons from electrons in the magnet elements is performed. Subsequent tracking of these photons is of course also possible. The generation and tracking of SR leads to energy deposition in the beam-line elements, as shown in Fig. 1. Similarly, the beam halo can be tracked down the beam delivery system, including the effects of scattering in spoilers and absorbers, where peaks in the energy deposition can be observed, as shown in Fig. 2.

Muons are produced at the ILC when halo electrons shower in the collimators. There are several production mechanisms, including the Bethe-Heitler process and electron-positron annihilation. Initial `BDSIM` studies have concentrated on the Bethe-Heitler process and the energy distribution of muons produced by this process from 500 GeV electromagnetic showers are shown in Fig. 3. These Bethe-Heitler muons were then tracked using `BDSIM` and the ILC beam delivery lattice from the collimation region to the IP within a 2 m concrete tunnel. Assuming a halo of 10^{-3}, or 2×10^7 halo electrons per bunch, results in approximately 144 muons reaching the detector per bunch.

As is already known, the number of muons reaching the detector can be reduced by introducing iron spoilers into the tunnel. For the ILC deck with collimators at $z = 624$ m and $z = 1532$ m from the linac exit, and the IP at $z = 1981$ m, the muon rates shown in Tab. I were obtained. Here SP1 is an iron spoiler of length 9 m and radius equal to that of the tunnel located just after the $z = 624$ m collimator and SP2 is a similar spoiler, but of length 18 m and located after the $z = 1532$ m collimator. The magnetic fields chosen for the muon spoilers are 0 and ± 1T.

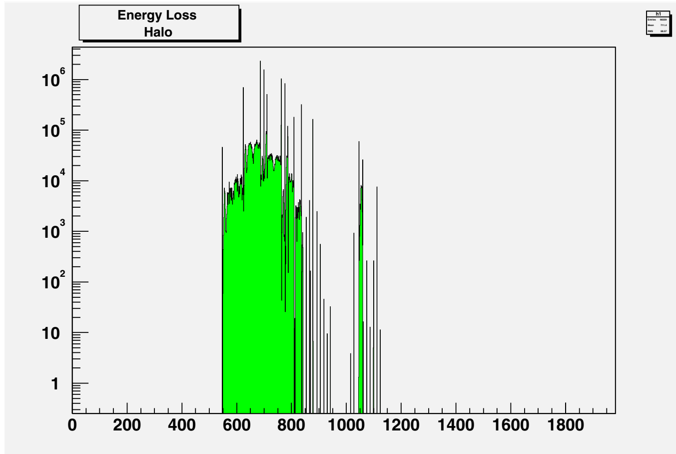

Figure 2: Deposition of energy from beam halo losses along the beam-line in GeV/m for the ILC beam delivery system. The Linac exit is at $z = 0$.

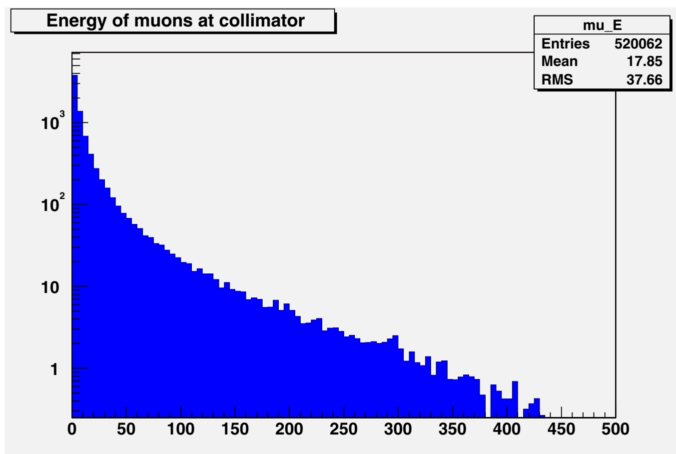

Figure 3: Muon energy distribution (in GeV) arising from 500 GeV electron showers in iron.

The greatest reduction in muon rates is obtained when the spoilers are magnetised and with opposite polarities.

4. INTERACTION REGION

A useful recent addition to the functionality of BDSIM is a common format interface for the interaction region descriptions with those of the detector groups. This will allow fast turn-around of simulations and optimisation of this region and so improve the development of machine-detector-interface issues. A example of a preliminary study of the interaction region using BDSIM is a simulation of the splash-back arising from the SR of beam-halo electrons hitting the downstream quads as shown in Fig. 4.

5. SUMMARY

BDSIM is a flexible and powerful tool for beam-line simulation. In addition to the processes and applications described above, the program is also being used to simulate and optimise various beam diagnostics systems, including laser-wires and energy spectrometers. All these studies are currently ongoing. Future work will also include studies

Table I: Relative numbers of muons reaching the detector as a function of muon creation point, inclusion of muon spoilers SP1 and SP2 as described in the text, and magnetisation of the spoilers.

Initial z	**SP1 (Field/T)**	**SP2 (Field/T)**	**Relative μ Flux**
1532	None	None	1.0
1532	None	0	0.7
1532	None	1	0.7
624	None	None	0.5
624	0	0	0.2
624	1	1	0.2
624	1	-1	0.1

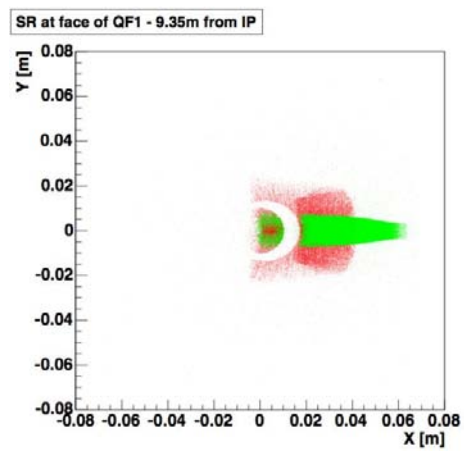

Figure 4: Splash-back at the IP from the SR of beam-halo. In green (light grey) are the splashback photons from the first downstream quad whereas in red (dark grey) are the SR photons from the two upstream quads. The white crescent is the shadow of the beampipe.

of back-shine of neutrons from the beam-dumps and other background processes; with this in mind experience is currently being gained of running BDSIM on the GRID.

Acknowledgments

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