Implementation of CERN secondary beam lines T9 and T10 in BDSIM

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Abstract. CERN has a unique set of secondary beam lines, which deliver particles extracted from the PS and SPS accelerators after their interaction with a target material reaching energies up to 400 GeV. These beam lines provide a crucial contribution for test beam facilities, and host several fixed target experiments. A correct operation of the beam lines requires precise simulations of the beam optics and studies on the beam-matter interaction, radiation protection, beam equipment survival etc. BDSIM combines tracking studies with energy deposition and beam-matter interaction simulations within one software framework. This paper presents studies conducted on secondary beam lines with BDSIM for the beam lines T9 and T10. We report the tracking analysis and the energy deposition along the beam line. Tracking analysis validation is demonstrated via comparison to existing tracking codes.

1. INTRODUCTION

Beam Delivery Simulation (BDSIM) [1] is an open source software developed at Royal Holloway, University of London. It is a C++ program that utilises the Geant4 toolkit to simulate both the transport of particles in an accelerator and their interaction with the material. BDSIM is capable of simulating a wide variety of accelerator components and magnets with Geant4 geometry dynamically built based on a text input file. Thick lens accelerator tracking routines are provided for fast accurate tracking in a vacuum. The flexibility and quick conversion characteristics of the software found applications in various accelerator physics related projects. Secondary beam lines at CERN are utilised as a facility for test beams and fixed target physics experiment. These lines have beam parameters that are adaptable on a fast timescale. The configuration of beam line elements, user infrastructure and the settings of the magnets are easily adjustable according to users’ needs. In this context BDSIM represents a useful tool given its versatility.

This paper presents studies on secondary beam lines simulated with this software. The secondary beam lines subject to these studies are T9 and T10 located in the East Area on the Meyrin site of CERN, see Figure 1. Studies include: optics, energy deposition and beam composition for both beam lines. In this paper, T10 optics is presented while for T9, studies on energy deposition and particles production. The East Area beam lines are currently under renovation for the operation after year 2021. The present paper describes the simulation of the beam line state before the renovation start.
2. T9 AND T10 BEAM LINES

The beam lines are located in building 157, see Figure 2, and have their origins on the same target, the so called multi-target [2]. These two lines provide secondary beams of charged particles (typically $\mu$, $\pi$, p and e) in a momentum range from 1 GeV/c up to 10 GeV/c (for T9 beamline) and up to 6 GeV/c (T10 beamline), produced due to interaction of a primary 24 GeV/c proton beam with the target. The beam structure foresees typical intensities in the order of $10^3$-$10^6$ particles per extraction cycle (spill) for a spill duration of $\sim$ 400 ms with a repetition period of about 20 s.

![Figure 1: CERN complex scheme with arrow pointing at the East Area (bottom-right).](image1)

![Figure 2: T9 and T10 in the East Area.](image2)

T9 and T10 play an important role in the CERN complex. Mostly, the beam lines’ operation is for test-beam runs, at the moment T9 is used for several experiments while T10 has been used mainly for ALICE. In the beginning of the century, T9 hosted the HARP [3] experiment for neutrino physics studies, this work provided data for neutrino fluxes characterization. Moreover, recently, T9 found application in the Beamline for Schools (BL4S) project. With this this spectra of activities, a high-precision characterization of beam and losses is fundamental.

3. OPTICS

In the past, three software codes were used for the East Area secondary beam lines studies, TRANSPORT, TURTLE and BEATCH [4][5][6]. TRANSPORT is utilised for optics calculations, TURTLE for particle tracking whilst BEATCH for the creation of geometrical layout file. The input files for these software codes are all available on a CERN database [7]. Files used for the simulations presented in this paper contain information of the beam lines status since 2006.

BDSIM offers a fast converter from TRANSPORT to MADX [8] or BDSIM, this converter is part of the capabilities of the module pybdsim. Using pybdsim the optics of T9 and T10 have been extracted from the TRANSPORT file and written to both a MADX and a BDSIM file. At this point a comparison between MADX and BDSIM is possible.

3.1. T10 beam line optics

As already mentioned in the introduction, optics in this section are relative to T10 beam line only. The beam in T10 is a 6 GeV/c protons beam with an emittance of the order of $10^6$ m rad in both x and y planes. In order to validate the optics, 10000 particles have been tracked in BDSIM and their positions have been compared with the output of MADX. The reported plots for optics (Figure 3 and Figure 4) are relative to betas (twiss parameter $\beta$) and the dispersion (D) in both planes.
In both figures a good agreement between MADX and BDSIM can be seen. The result is particularly relevant since the two software codes use a different approach in optics calculation. MADX uses the matrix multiplication method, while BDSIM a back-tracking approach. In that sense BDSIM, draws particles’ coordinates assuming a certain distribution (in this case a Gaussian distribution), afterwards calculating the particles’ momenta to estimate the parameters of the distribution.

A primary particle is here referred to as a particle that is simulated as part of the initial beam. BDSIM includes a useful module, rebdsim, this module is useful for data management and analysis. In particular, is possible to fast check the primaries distribution thanks to the option rebdsimOptics. With this module is possible to quickly generate plots for primaries distribution. Figure 5 depicts two plots of the weighted momentum ($\Delta p/p_0$, where $p_0$ is the absolute value of the momentum and $\Delta p$ the momentum spread) distributions in x and y.

4. INTERACTIONS
Up to this point only T10 beam line was considered. For calculation of the energy deposition and beam characterization studies, a model including the region upstream of the target has been used. This region is common for T9 and T10 and is called F61N, see Figure 6.

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**Figure 3**: Beta functions in x and y as function of s. Comparison between MADX and BDSIM.

**Figure 4**: Dispersion in x and y as function of s. Comparison between MADX and BDSIM.

**Figure 5**: Correlations at primaries. Normalized momentum in x and y in function of x and y.
The multi-target can be used in 5 different settings to provide the desired beam compositions. The configuration used for simulations in this paper is for electron-beam and is a two-layered target. The two layers have a cylindrical shape and are disposed adjacent to each other. The first cylinder is 200 mm long and is made of beryllium (Be), the second is 3 mm long and made of tungsten (W). For the purpose of studying the beam composition 10 million particles have been simulated using a complete package of physics processes available in BDSIM. The spectra 5 m after the target, is analysed for some particle species and plotted as a function of the relative energy, see Figure 7.

The plot in Figure 7 shows cumulative spectra for all particles, primary protons, secondary protons, pions, electrons and gammas. Other hadrons generated in the process have not been included in the displayed spectra as they account only for a small portion of the flux, i.e. kaons, neutral pions, etc.

These aforementioned results have been used as an input for a simulation with 10 million particles for the complete beam lines F61N and T9. In Figure 8 can be seen the spectra at the last bending magnet of T9. At this position there are no beam pipes present and particles travel in air and possibly gas, if Cherenkov counters are utilised. Once again, it can be seen that secondary protons survive the collision on target and that the beam comprises a share of electrons. Pions represent a component of the beam and have higher spectra than electrons for higher energies. The energy losses along the particles path have been studied with the previous model, results can be seen in Figure 9. As expected, can be seen a peak of losses is in the target region (s = 24.96 m), followed by losses in the rest of the beam line.
5. CONCLUSION
The present paper summarizes studies conducted in BDSIM for CERN secondary beam lines in the East Area. The capabilities of the software to simulate optics is confirmed given comparison with MADX. Particles spectra and beam composition is studied with energy deposition along the beam line. BDSIM confirms to be a useful and versatile tool for these studies. Results presented in this paper can be used for precise calibration of instruments and baseline for data simulations in future experiments in East Area. Studies for benchmarking simulations to measurements are undergoing, altogether with comparison to existing beam-matter interaction simulation tools.

ACKNOWLEDGEMENTS
This work has been possible with the contribution of colleagues at CERN. In particular, thanks to Lau Gatignon for his fundamental help and colleagues in the EN-EA group for interesting discussions on secondary beam lines. Thanks as well to the engineers of the section for providing the models of the East Area beam lines.

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