ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPGW069

IMPLEMENTATION OF CERN SECONDARY BEAM LINES T9 AND T10 IN BDSIM

G. D'Alessandro[1†], S.T. Boogert, S.M. Gibson, L.J. Nevay, W. Shields, John Adams Institute, Royal Holloway University of London, Egham, UK
J. Bernhard, A. Gerbershagen, M.S. Rosenthal, CERN, Geneva, Switzerland
[1]also at CERN, Geneva, Switzerland

Abstract

CERN has a unique set of secondary beam lines, which deliver particle beams extracted from the PS and SPS accelerators after their interaction with a target, 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 beams 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 code.

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 lines state before the renovation start.

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 μ, π, p and e) in a momentum range from 1 GeV/c up to 10 GeV/c (for T9 beam line) and up to 6 GeV/c (T10 beam line), 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 ~ 400 ms with a repetition period of about 20 s.

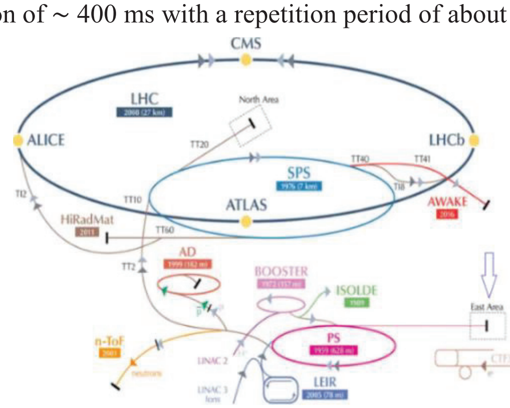

Figure 1: CERN complex scheme with arrow pointing at the East Area (bottom-right).

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.

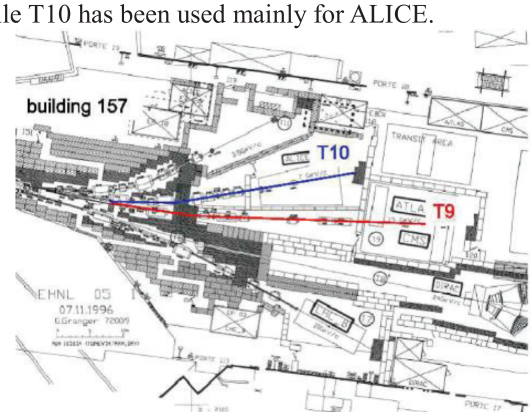

Figure 2: T9 and T10 in the East Area.

† gian.dalessandro.2018@live.rhul.ac.uk.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPGW069

In the beginning of the century, T9 hosted the HARP [3] experiment for neutrino physics studies and provided data for neutrino fluxes characterisation. Moreover, recently T9 found application in the Beamline for Schools (BL4S) project. Within this spectrum of activities, a high-precision characterisation of beam and losses is fundamental.

OPTICS

In the past, three software codes were used for the East Area secondary beam line studies, TRANSPORT, TURTLE and BEATCH [4-6]. TRANSPORT is utilised for optics calculations, TURTLE for particle tracking whilst BEATCH is used 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 article 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, which was used to extract the optics of T9 and T10 from the TRANSPORT file to both a MADX and a BDSIM file, respectively. At this point a comparison between MADX and BDSIM is possible.

T10 Beam Line Optics

As already mentioned in the introduction, optics in this section refer to the T10 beam line only. The beam in T10 is a secondary 6 GeV/c 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 protons 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 show the optical function betas (twiss parameter β) and the dispersion (D) in both planes.

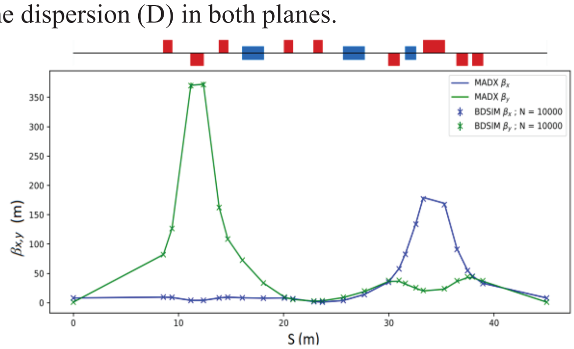

Figure 3: Beta functions in x and y as function of s. Comparison between MADX and BDSIM.

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 is using a back-tracking approach. In that sense BDSIM traces particle coordinates assuming a certain distribution (in this case a Gaussian distribution) and afterwards calculates particle momenta to estimate the parameters of the distribution.

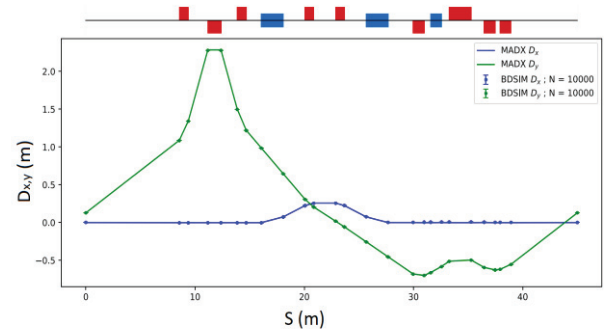

Figure 4: Dispersion in x and y as function of s. Comparison between MADX and BDSIM.

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

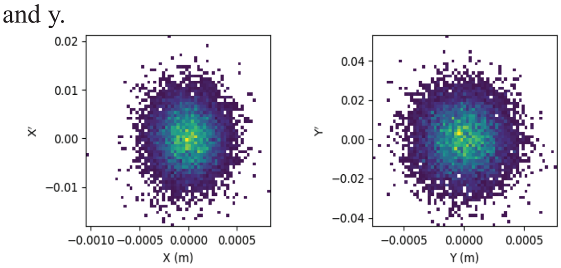

Figure 5: Correlations at primaries. Normalised momentum in x and y in function of x and y.

INTERACTIONS

Up to this point only the T10 beam line was considered. For calculation of energy depositions and beam characterisation 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.

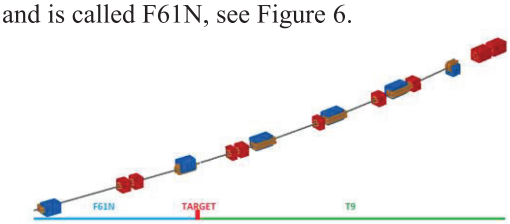

Figure 6: F61N and T9 beam lines in BDSIM visualizer.

Particles Spectra after Target

The multi-target can be used in 5 different settings to provide different beam compositions. The configuration used for simulations in this paper is used for electron-rich beams and comprises a two-layered target. The two layers have a cylindrical shape and are placed 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 tung-

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPGW069

sten (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 at 5 m downstream of the target are analysed for selected particle species and plotted as a function of the relative energy, see Figure 7.

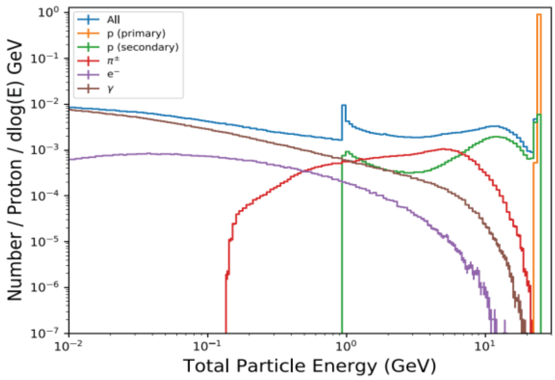

Figure 7: Particle spectra 5 m downstream the target.

The plot in Figure 7 shows cumulative spectra for all particles, primary protons, secondary protons, pions, electrons, and photons. 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.

F61N and T9 Particles Spectra and Losses

These aforementioned results have been used as an input for a simulation with 10 million particles for the complete beam lines F61N and T9.

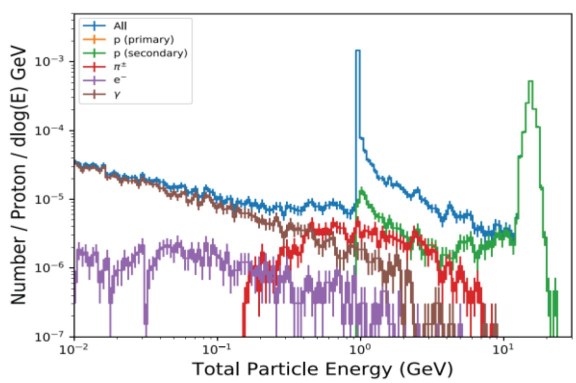

Figure 8: Spectra at the last bending magnet of T9 beam line.

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 a higher flux 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.

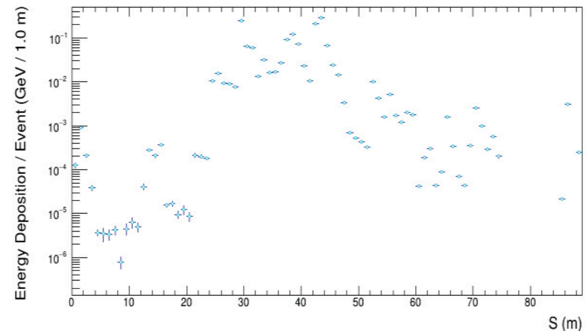

Figure 9: Losses in F61N and T9 beam line.

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.

CONCLUSION

The present paper summarises studies conducted in BDSIM for CERN secondary beam lines in the East Area. The capability of the software to simulate optics is confirmed by comparison with MADX. Particles spectra and beam composition are 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 calibration of instruments and serve as the baseline for data simulations for the future exploitation of the East Area. Studies for benchmarking simulations to measurements are undergoing, together 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 and technicians of the section for providing the models of the East Area beam lines.

REFERENCES

[1] BDSIM, `http://www.pp.rhul.ac.uk/bdsim/manual/`

[2] Multi-Target, `http://sba.web.cern.ch/sba/targets/TargetNorth.html`

[3] L.Durieu *et al.*, "Optics studies for the T9 beam line in the CERN PS east area secondary beam facility", in *Proc. 19th IEEE PAC 2001*, 18-22 Jun 2001, Chicago, Illinois, pp.1547- 1549. `doi:10.1109/PAC.2001.986743`

[4] TRANSPORT, `https://cds.cern.ch/record/186282`

[5] TURTLE, `http://extbeams.fnal.gov/users/bacfish/hp/docs/Turtle%20Guide%20slac-r-544.pdf`

[6] G. Burton *et al.*, "BEATCH-A FORTRAN programme for the particle optics of beam transfer channels", CERN Document Server, 30 May 1969, CERN, Geneva, Switzerland, pp. 2-10.

[7] Database, `http://sba.we.cern.ch/sba/beamsandareas/east/east.htm`

[8] MADX, `http://mad.web.cern.ch/mad/`