

IMPLEMENTATION OF MAD-X INTO MUSIM

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Abstract

MuSim is a new and innovative graphical system that allows the user to design, optimize, analyze, and evaluate accelerator and particle systems efficiently. It is designed for both students and experienced physicists to use in dealing with the many modeling tools and their different description languages and data formats. G4beamline [1] and MCNP [2] have been implemented into MuSim in previous studies. In this work, we implement MAD-X [3] into MuSim so that the users can easily use the graphical interface to design beam lines with MAD-X and compare the modeling results of different codes.

INTRODUCTION

There are many particle simulations codes available for accelerator and detector simulations. Most of them have unique and inconvenient user interfaces. The aim of MuSim is to provide a graphical user interface for the user to easily construct, simulate and compare many particle simulations. It has a 3-D viewer to display the scheme as the user constructs it. All objects, such as magnets, tubes, radio frequency cavities and detectors, can be simply dragged and dropped from the element list to the scheme. This is much more flexible and intuitive than the geometry specifications of many simulation codes using command lines. MuSim provides both global and beamline coordinates so that the user can easily choose either of them for specific systems.

MAD-X is one of the most popular codes in accelerator design and simulation. It is a general purpose accelerator and lattice design program. It reads a command line style file in which the user defines the properties of all machine elements, then calculate the optics parameters, compute the desired properties of such a machine, and simulate the beam dynamics in the designed machine. The file formats of MAD-X have been adopted by other, related simulation codes, making this interface usable for other codes as well. MAD-X has a graphic output package to output the beam parameters, but it has no graphical viewer to check the designed physical scheme.

In this work, we implement MAD-X into MuSim to combine the advantages of the two: the user can benefit from the friendly user interface of MuSim to easily design the accelerator system and use the sophisticated modules of MAD-X to simulate the beam dynamics without learning the complicated input formats of MAD-X. The users can also easily compare the simulation results between MAD-X and other simulation codes such as G4beamline and MCNP, regardless of their different input and output file formats.

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3D MAD-X

MuSim provides a unified command list to define the particle source, the beam line elements and the system coordinates for all available codes. In the "Edit" page of MuSim, the users can specify the parameters of all these elements. Figure 1 shows a single cell of a storage ring, consisting of two quadruples and a bending dipole magnet. The elements can be placed in both global coordinates and beamline coordinates, if the simulating code that the user chooses can accept them. In case of using MAD-X, only beamline coordinates can be used. The S-axis (white line) of the beamline coordinates follows the centerline of the beamline, and is bent by the bending magnets just like the reference particle; the cells are simply placed sequentially along the S axis.

Various beamline elements including drift tube, solenoid, dipole, quadruple, multiple magnet, pillbox cavity, and detectors, can be easily chosen from the command list. All their parameters are specified right after they are chosen. The command list also has several solids that MAD-X does not accept but can be used in other codes. In this case, an error message will be alarmed if the user chooses MAD-X as the simulation program.

SIMULATION CHOICES

After editing and saving the beamline elements, the user can click on the "Simulate" icon to switch to the simulation page. Figure 2 shows the simulation of a bunch of electrons passing through three quadruples. A set of detectors (yellow rings) are put along the beam line to record the beam parameters that are calculated by the simulating code. The white disk is a beam dump to stop all the particles at the end. The user can simply choose the simulating program from the drop down menu to run the simulation, and the trajectories can be displayed after the system has been simulated by a specified program.

Another advantage of MuSim are its sliders. As shown in Fig. 2, the user can vary the beam line parameters easily by either the sliders or directly the input box. The result will be shown in the 3D viewer instantly. This is a great advantage for designing beam lines.

ANALYSIS

After being simulated, the particles are recorded by the detectors along the beam line. The parameters of the particles, such as position, time, momentum, event id number, PDG id number, and field strengths (in the extended mode), are all recorded as a tree for one detector in a ROOT [4] file, regardless of which simulation code has been chosen.

Here is an example of using two codes (MAD-X and G4beamline) in MuSim to simulate a beam dynamic in a

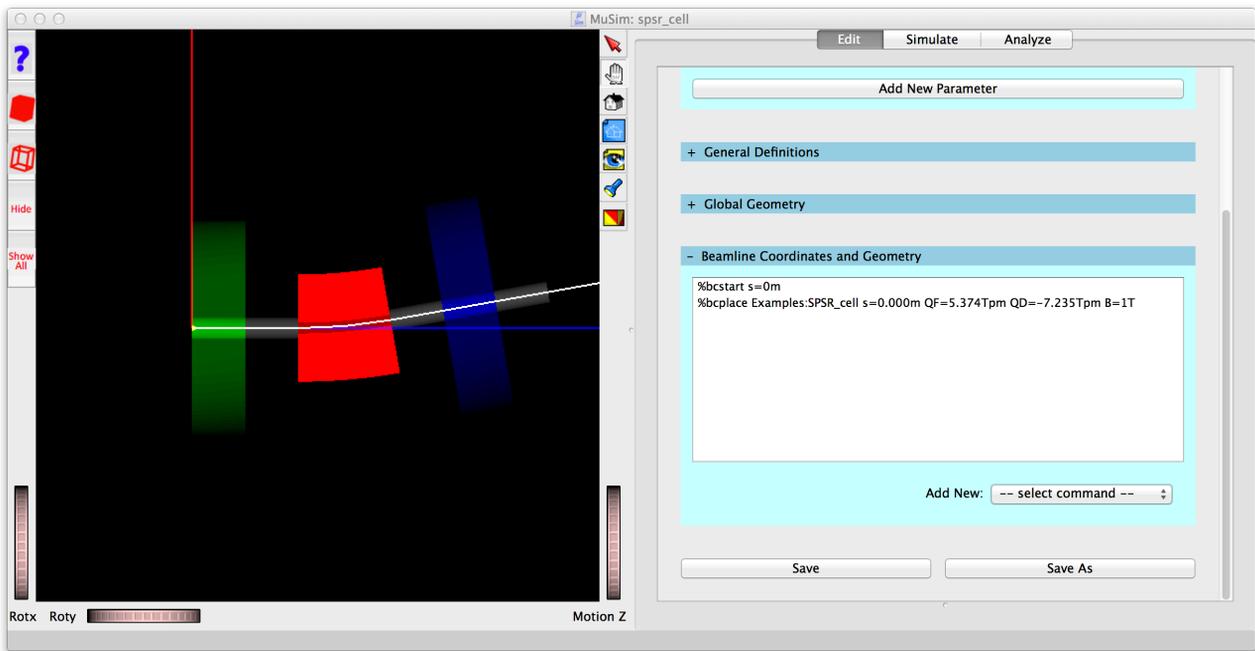


Figure 1: MuSim editing a single cell of a storage ring.

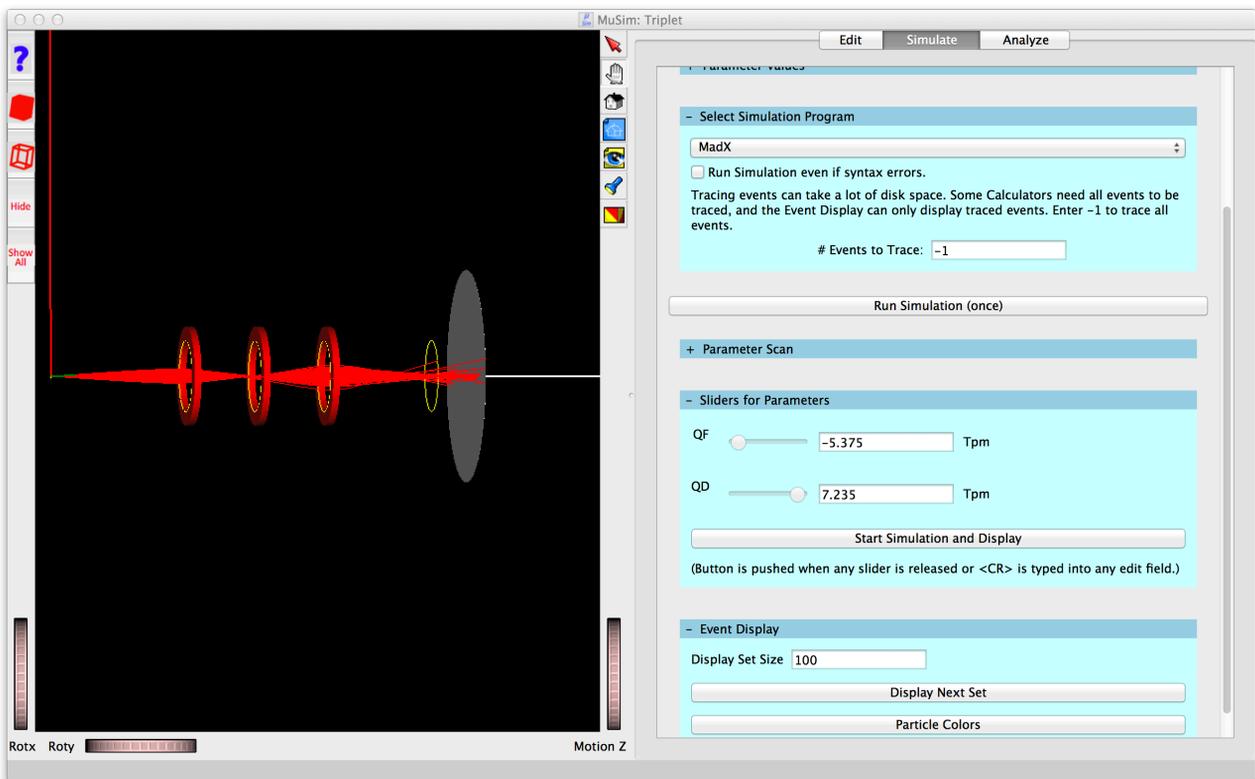


Figure 2: MuSim displaying trajectories of electrons passing through a set of quadrupoles.

channel with high order fields. Figure 3 shows a section of the parametric-resonance ionization cooling (PIC) channel [5]. The snake-like tube has dipole, quadrupole, skew-quadrupole, sextuple, and skew-sextuple fields in it. The muon beam is focused at the end of each period. We com-

pare the tracking of muons in such a complex channel by G4beamline and MAD-X. Figure 4 shows the trajectory of the reference particle in the PIC channel. In MAD-X, the reference particle follows the centerline perfectly since MAD-X expands EM fields around the centerline. How-

5: Beam Dynamics and EM Fields

D11 - Code Developments and Simulation Techniques

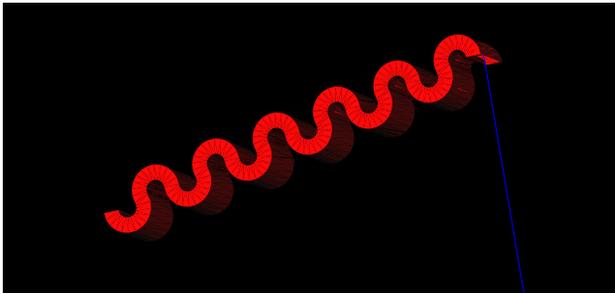


Figure 3: A section of the parametric-resonance ionization cooling (PIC) channel.

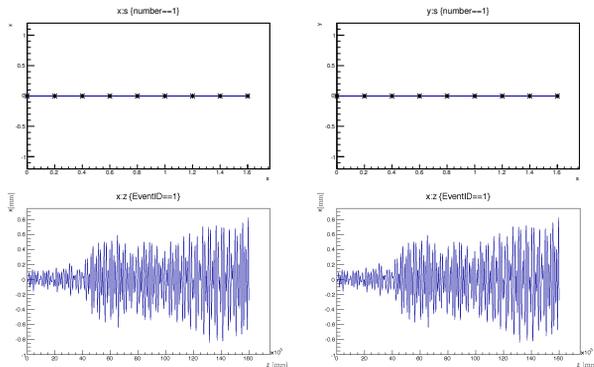


Figure 4: Tracking of the reference particle in the PIC channel by MAD-X (upper plots) and G4beamline (lower plots). Left plot: x versus s trajectory. Right: y versus s trajectory.

ever, the reference particle oscillates around the centerline in G4beamline: as the tracking distance becomes longer, the tracking error becomes greater. This happens because G4beamline uses very different approximations than does MAD-X, with much more emphasis on realism. G4beamline integrates the equations of motion for the EM fields, while MAD-X assumes the EM fields are zero along the centerline (except for bends). Note the scale: the errors are less than 1 mm after 160 meters.

The fact that different simulation codes use such very different approximations is one of the advantages of using MuSim: It is simple to compare results from multiple codes simulating a single system.

Figure 5 shows the tracking of a gaussian distributed muon beam in the above PIC channel. The beam information is recorded at certain s positions along the channel. The

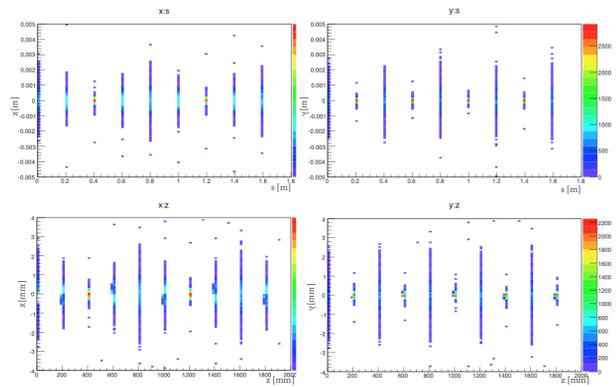


Figure 5: Tracking of a muon beam with a gaussian spatial distribution in the PIC channel by MAD-X (upper plots) and G4beamline (lower plots). Left plot: x versus s distribution. Right: y versus s distribution. Color represents the muon density.

upper plots are results from MAD-X, and the lower plots are simulated by G4beamline. The beam dynamics simulated by the two codes shows excellent agreement in such a complex channel.

CONCLUSION

MAD-X has been interfaced into MuSim, which packages several beamline design codes. MuSim gives a friendly user interface to the system being simulated, and the 3-D viewer of MuSim visualizes MAD-X. The sliders of MuSim makes MAD-X more convenient for beamline design. The unified output file format makes it easy to analyze and compare the results from different simulation codes.

REFERENCES

- [1] G4beamline: <http://g4beamline.muonsinc.com>
- [2] MCNP: <https://mcnp.lanl.gov/>
- [3] MAD-X: <http://mad.web.cern.ch/mad/>
- [4] Root: <https://root.cern.ch>
- [5] Y. Bao *et al.*, "Simulation of a skew parametric resonance ionization cooling channel", presented at NAPAC2016, Chicago, IL, USA, paper WEPOA54.