

# G4BEAMLINE SIMULATION PROGRAM FOR MATTER-DOMINATED BEAMLINES\*

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## Abstract

G4beamline is a single-particle simulation program optimized for the design and evaluation of beam lines. It is based on the Geant4 toolkit [1], and can implement accurate and realistic simulations of particle transport in both EM fields and matter. This makes it particularly well suited for studies of muon collider and neutrino factory design concepts. G4beamline includes a rich repertoire of beamline elements and is intended to be used directly, without C++ programming, by accelerator physicists. The program has been enhanced to handle a large class of beamline and detector systems, and is available on Linux, Windows, and Macintosh platforms.

## INTRODUCTION

Potential new facilities such as neutrino factories and muon colliders present new and interesting problems in accelerator physics involving both the decay of unstable particles and the traversal of matter. Realistic modeling of such systems requires the simulation of individual particle behavior in both matter and electromagnetic fields. As most accelerator physics programs handle neither decays nor materials, G4beamline has been developed to provide a flexible, user-friendly program to perform such simulations without user programming. By using the Geant4 toolkit [1], it incorporates most of what is known about the interactions of particles in matter, as well as their decays and behavior in EM fields.

## DESCRIPTION

A key advantage of using G4beamline is that its description of the simulation is commensurate with the complexity of the system being simulated, instead of being a significantly more complicated custom C++ program. Other important aspects are:

- A physicist-readable ASCII file to specify the simulation, with auxiliary files for field maps, etc.
- A rich repertoire of beamline elements that can be combined to define new and customized elements
- A general set of initial beam specifications (including a cosmic-ray muon “beam” and external files)
- Beam tracks can be input and output using several formats including ASCII and Root [2] files
- Many parameters can be automatically tuned (RF cavity timing and gradients, bending magnet fields, etc.)

- Visualization of the system is included, using many viewers (OpenGL, VRML, Open Inventor, etc.)
- Support for parallel jobs on multiple CPUs
- The historoot program, which makes it easy for non-experts to generate Root histograms and plots

The basic structure of a simulation is to first define the beamline elements to be used (magnets, RF cavities, etc.), including their geometry, materials, and local fields. Then these elements are placed into the world, usually along the nominal beam centerline; each placement can have a position, rotation, and its own field value. Parameters for the elements can be defined in the input file or on the command line, so scripting is straightforward. Individual particles can be traced, beam profiles can be generated and displayed, and virtual detectors can be used to sample the beam at any point.

The tracking of particles through the simulated system is as accurate and realistic as the Geant4 toolkit implements. The input file selects from any of the Geant4 physics use cases, and can set values for the various Geant4 tracking-accuracy parameters. This permits users to make trade-offs between CPU time and simulation accuracy. Similarly, G4Beamline permits the specification of magnetic map parameters, permitting a trade-off between memory usage (and the CPU time to generate the map) and simulation accuracy.

While G4Beamline can make it rather simple to specify a simulation, it cannot substitute for knowledge and experience about the problem domain or about particle-tracking simulations in general. Like all computer programs, G4Beamline is prone to “garbage in, garbage out”, especially when used by unskilled users. It is strongly suggested that visualization be used to verify the geometry of the simulation and that a handful of particles be tracked properly through it. Whenever possible one should arrange to track through a simple geometry that can be compared to independent results, to make sure that what one thinks is happening actually does occur in the simulation.

## EXAMPLES

Figures 1-7 show the G4beamline graphical user interface and some of the many systems that have been simulated.

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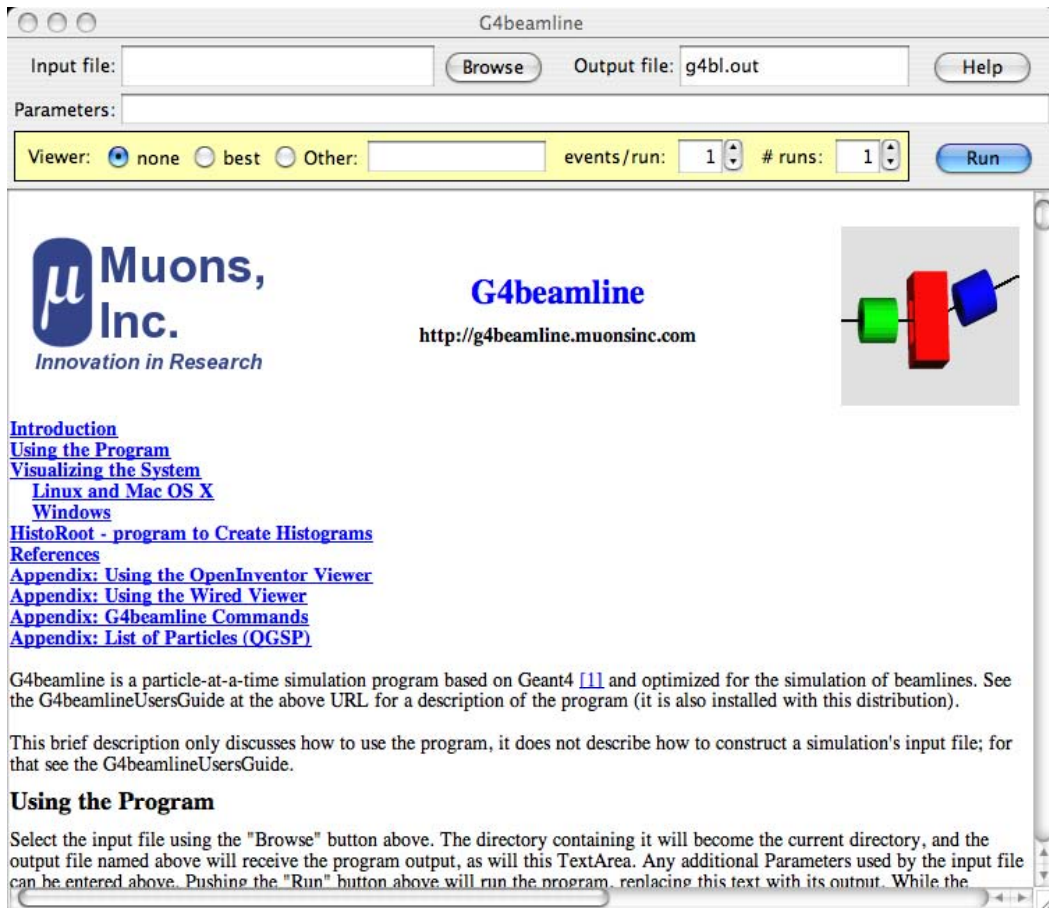


Figure 1: The G4beamline graphical user interface.



Figure 2: The MICE muon beamline and cooling channel [3] – a detailed and realistic simulation using G4beamline. Quadrupoles are green (HF) and blue (HD), dipoles are red, solenoids are yellow, beam pipes are gray, vacuum chambers are white, the two RF cavities are gray, and the calorimeter at the end is light blue. The pion production target is at the top left inside the ISIS synchrotron (not shown).

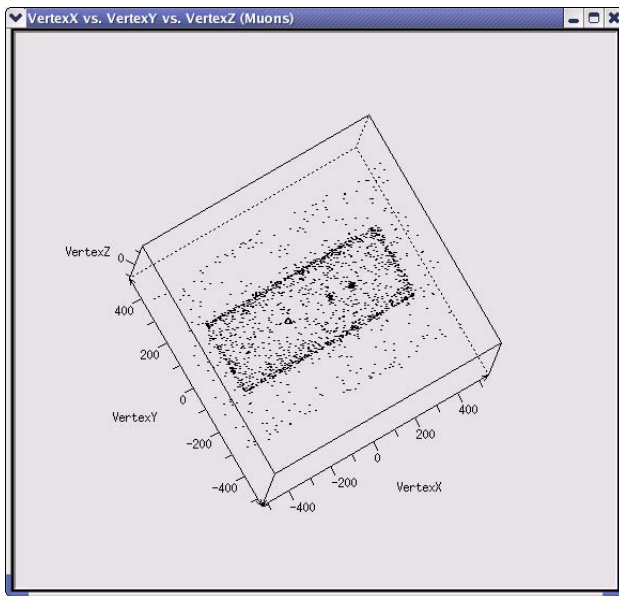


Figure 3: Cosmic Ray muons scanning a shipping container.

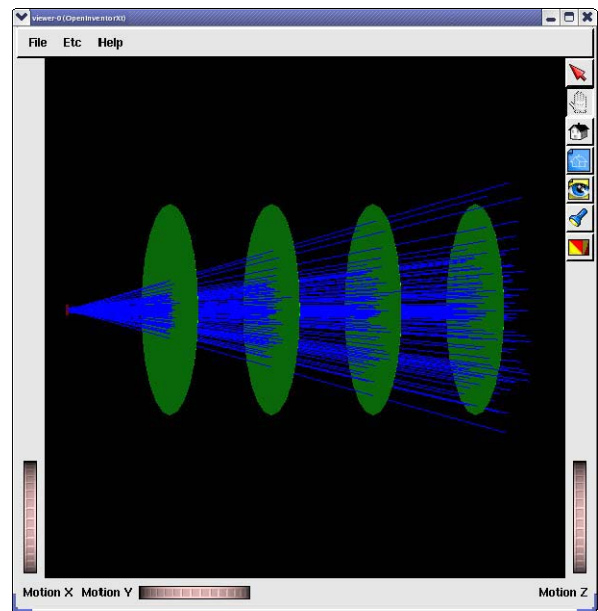


Figure 6: example1.in – a simple Gaussian beam into four circular detectors.

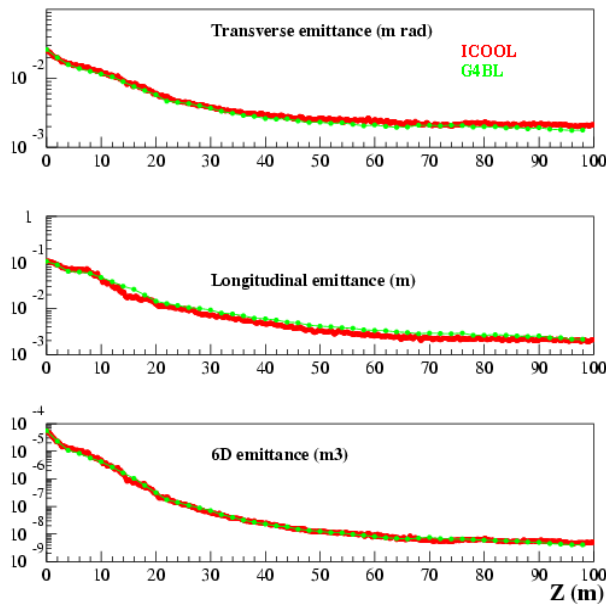


Figure 4: Emittance evolution in a Helical Cooling Channel.

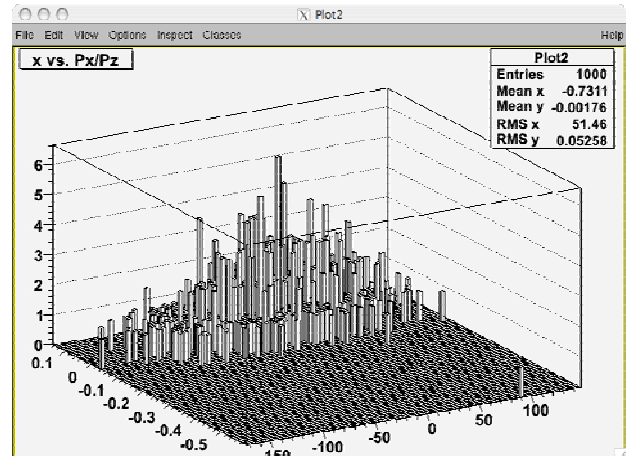


Figure 7: A 2-D histogram showing the outlier event that greatly affects the emittance computation.

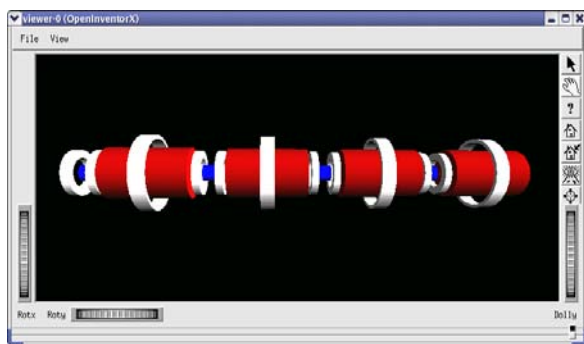


Figure 5: A section of the Study 2 SFOFO cooling channel. Solenoids are white, RF cavities are red, and the liquid hydrogen absorbers are blue.

### SUMMARY

G4beamline has been in use for several years by a half-dozen research groups to simulate several dozen different systems. It has achieved its goal of being easy to use, and the learning curve for experienced accelerator physicists is rather short for a program of this scope. With sufficient attention to detail, it is possible to make the simulation quite realistic. The development of G4beamline is ongoing, and its features and facilities are expanding. Comments and suggestions from potential or actual users are welcome (see <http://g4beamline.muonsinc.com>).

### REFERENCES

- [1] <http://geant4.cern.ch>.
- [2] <http://root.cern.ch>.
- [3] <http://mice.iit.edu>