

# USING GRAPHIC-TURTLE WITH THE PARTICLE BEAM OPTICS LABORATORY (PBO LAB™)

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## Abstract

A Particle Beam Optics Laboratory (PBO Lab™) module has been developed for the Paul Scherrer Institute (PSI) version of the TURTLE program commonly known as Graphic-Turtle. The PSI-TURTLE version extends the original TURTLE program by including several unique beam optics capabilities, as well as by providing a self-contained graphics package. The unique optics modeling, together with the data visualization enhancements, make the PSI-TURTLE program ideal for certain types of beam simulations. The PBO Lab environment provides a single graphic user interface (GUI) that features an easy-to-learn and easy-to-use drag-and-drop beamline construction kit. Underlying the GUI is a sophisticated object model developed specifically for the accelerator community. PBO Lab provides a common interface for multiple charged particle optics codes. Modules have been developed for a number of popular beam optics programs that cover a range of accelerator types and applications. The PSI-TURTLE Module extends those capabilities. The Module is described and its main features and limitations are summarized.

## INTRODUCTION

TURTLE (Trace Unlimited Rays Through Lumped Elements) is a program that simulates the multi-particle transport of beams through transfer lines and certain accelerator components [1]. The simulation of aberrations and other non-linear effects, such as beam encounters with apertures, have made TURTLE a standard tool for evaluating the performance of accelerator beamlines. The PSI-TURTLE version [2, 3] extends the capabilities of the standard TURTLE code. The extensions can be divided into two categories: (i) beam physics models and (ii) data visualization capabilities. Both of these are discussed below.

The Open Architecture Software Integration System (OASIS™) was used to incorporate the PSI-TURTLE program into the PBO Lab framework. The OASIS Module Builder [4] is a specialized PBO Lab Module that is used to create new PBO Lab Modules. The same GUI elements and related object model are utilized to define new attributes for these objects. These new attributes then form the software basis for the new module. The OASIS Module Builder requires no new code, or recompiling of existing code, and provides an easy method for adding charged particle optics programs to the suite of PBO Lab Modules.

## MODULE DEVELOPED WITH OASIS

### *The OASIS Module Specification*

The new attributes assigned to the PBO Lab GUI elements using the OASIS Module Builder collectively provide a Module Specification. The Module Specification is encapsulated into a text file (extension .olab), which can also include examples, test cases, etc. The OASIS Module Builder is also used to update, edit, or add attributes. When the development of a new Module is complete, the OASIS Module Builder is used to create an OASIS Module Specification file (extension .omod) which is utilized by PBO-Lab. When the PBO Lab application is started, the Module Specification file is loaded and all attributes and instructions defined for the Module are available. An executable version of the desired optics code (either .exe or .dll extension) is linked upon startup as well. A user manual for the OASIS Module Builder provides detailed instructions on the development procedure [5]. The complete Module consists of the optics code executable, e.g. turtle32.dll, and the Module Specification file, e.g. OASIS-PSI-TURTLE.omod. The OASIS Module Builder is not required to run the new Module - only PBO Lab with the optics executable and Module Specification file are used.

### *Unique Beam Physics Models*

The PSI-TURTLE program extends the capabilities of the original TURTLE code by incorporating additional charged particle beam modeling for: (a) electrostatic deflector (prism), (b) electrostatic quadrupole, (c) electrostatic accelerator (and einzel lens), (d) Wien filter, (e) general E×B separator, (f) dE/dx energy loss element, and (g) multiple, nuclear and absorption scattering.

It is beyond the scope of this work to describe each of these features, but note that objects for (a)-(c) were already available in PBO Lab to support other Modules [6] so their incorporation into the PSI-TURTLE Module via OASIS was similar to that used for other elements such as drifts, magnetic quadrupoles, etc. Items (d)-(g) required the use of OASIS to create objects that describe those elements. One example, for (g), is discussed below.

It should be noted that there are other beam optics element differences between PSI-TURTLE and TURTLE. For example, PSI-TURTLE includes a provision for the use of second-order Matsuda-Wollnik aberration integrals for magnetic and electrostatic quadrupoles [7]. This capability (including third-order) was previously incorporated into PBO Lab for other Modules and was

readily adapted for the PSI-TURTLE Module. Similar comments apply to several other differences between PSI-TURTLE and TURTLE.

### Unique Data Visualization Capabilities

A unique graphics package, compiled in the executable program gratur32.exe, is available for use with PSI-TURTLE. The package provides a useful extension for data visualization. A separate Module Specification file, OASIS-PSI-TURTLE-graphics.omod, was developed to implement this capability. However, it is a greatly simplified Module consisting of only a single menu command:

PSI-TURTLE Graphics → Write and Run Input (1)

The actual specification of the data to be displayed is defined in the main PSI-TURTLE Module. The PSI-TURTLE Module utilizes a set of Command Pieces to define the data output types and beamline locations for collecting the data. Other instructions for the simulation are also implemented using Command Pieces developed for running the PSI-TURTLE Module. Figure 1 shows the PBO Lab window that is used to access the Command Pieces of the PSI-TURTLE Module.

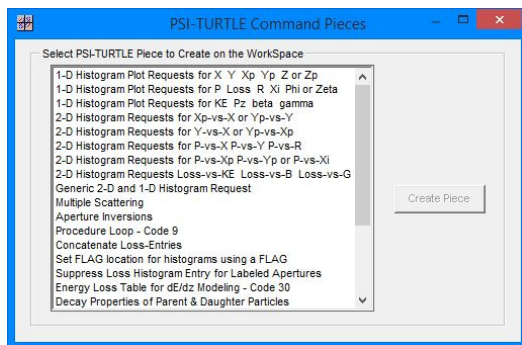


Figure 1: PBO Lab window used to select plot requests and other beamline location specific commands for the PSI-TURTLE Module. The scroll bar to the right is used to access other commands.

The list of commands shown in Fig. 1 illustrates an important feature of the PSI-TURTLE Module: easily read and understood language is used to identify the most commonly used commands. Users do not need any detailed knowledge of the turtle32.dll input file format or syntax for specifying the commands. The PSI-TURTLE Module writes all needed information to the input file (FOR001.DAT) used by the turtle32.dll in the required "positional format" notation used by Graphic-Turtle. See pages 172-194 of reference [1] for details of the "positional format" notation (aka the "original TRANSPORT notation"). After a PSI-TURTLE run for a specific problem is completed, then the execution of the menu command given in Equation (1) opens a gratur32.exe console window where the user selects the type of displays desired for each set of particle distribution data. This is followed automatically by the

visual displays selected. An example for a ring collimator is illustrated below.

### Limitations

As outlined above, the PSI version of the TURTLE program offers some unique capabilities when compared to the standard TURTLE program, but there are also some limitations. For example, when generating initial beam distributions from semi-axes parameters, only the initial beam correlations  $r_{12}$  and  $r_{34}$  are utilized by the turtle32.dll to generate the particle data. All other non-zero  $r_{ij}$  are ignored and thus effectively set to zero. To create an initial beam with such correlations, the PBO Lab DST-Converter Module can be used. That Module can read a distribution file created by other codes, such as PARMILA-2, MARYLIE, or the original TURTLE code, convert the data including such correlations to a distribution format usable by PSI-TURTLE, and then output the results to a data file readable by the turtle32.dll.

The PSI-TURTLE code also does not include computations for the longitudinal location of individual particles, sometimes referred to as the path length difference from the reference trajectory. This means that beam bunching or de-bunching effects are not modeled. The original TURTLE program can be used for such calculations.

## RING COLLIMATOR EXAMPLE

### PBO Lab Beamline Setup

A ring collimator beamline described by Rohrer is used to illustrate a typical simulation and is one of many examples used to benchmark the PBO Lab PSI-TURTLE Module. The ring collimator consists of a 30 cm long conical copper (Cu) rod, initially elliptical 1 cm high and 0.6 cm wide, increasing by 30% over the length. It is designed to hollow out a 590 MeV proton beam that is initially round with peak intensity at its center. Due to the asymmetry of the Cu rod cross section, the exiting hollow beam is expected to have an elliptical hole in the center.

The setup of the beamline in PBO Lab follows the same procedure used for any other optics code. The drag-and-drop beamline construction kit is used to define the beamline and to include location specific commands. Figure 2 illustrates the PBO Lab image for a ring collimator.

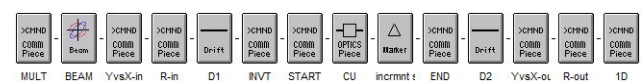


Figure 2: Icon representation of ring collimator built with the PBO Lab drag-and-drop beamline construction kit.

The simulation model represented by the Piece icons shown in Fig. 2 includes the initial beam description (BEAM), some distribution plot requests for the initial beam (YvsX-in, R-in), a drift (D1) followed by a copper rod scattering element (INVT, START, CU, increment

slit, END) and another drift (D2), finally ending with more beam distribution plot requests (YvsX-out, R-out) this time for the final beam. The Piece (MULT) at the beginning of the beamline model of Fig. 2 is a Command Piece that enables multiple scattering, nuclear elastic scattering and absorption in the simulation. Double-clicking an icon opens the PBO Lab Piece window that is used to input the detailed data for that element

### Simulation Results

One command of the PBO Lab PSI-TURTLE Module runs a simulation. PBO Lab writes the necessary input file (FOR001.DAT) used by the turtle32.dll, runs that program, and then opens the main text file output (FOR002.DAT). To visualize the results, the PBO Lab command of Eq. (1) is used, followed by inputting a few options into the gratur32.exe console window. Figure 3 shows typical results for the ring collimator.

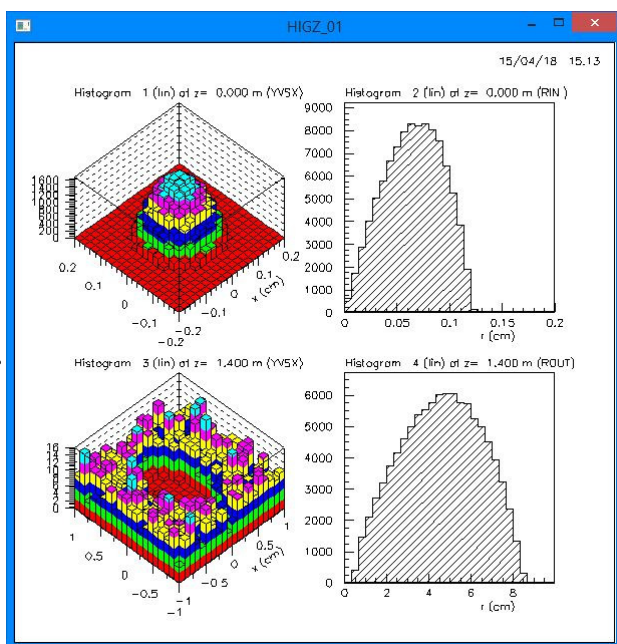


Figure 3: Beam cross section and radial distribution plots for the initial beam (top) and for the beam after the ring collimator (bottom). Note scale differences.

The initial beam (top) and final beam (bottom) plots shown in Fig. 3 demonstrate that the initially 1 mm round beam is scattered and hollowed out by the ring collimator. Another PBO Lab tool can be used to examine other views of the same data. Figure 4 illustrates the exit beam's cross section scatter plot that is invoked using another command of the PBO Lab PSI-TURTLE Module. The PBO Lab plot tool does not use gratur32.exe and provides an independent method to explore the beam distribution. The exit beam elliptical hole is clearly visible in Fig 4.

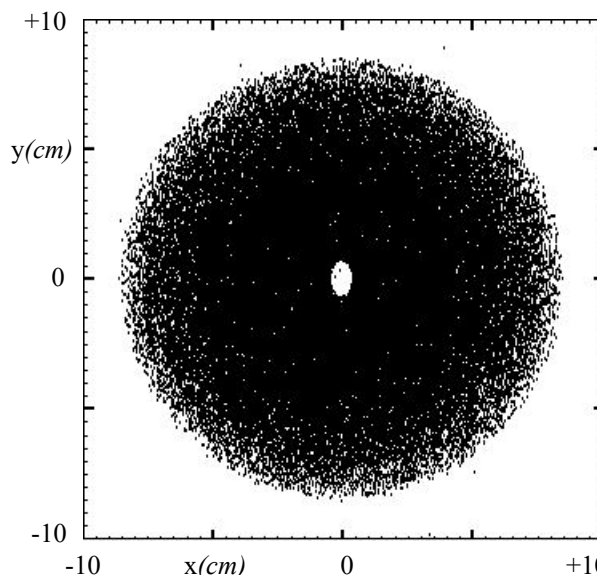


Figure 4: Cross section of the exit beam using the PBO Lab scatter plot Tool on the same data as used in Fig. 3.

### SUMMARY

Combining the PBO Lab interface with the PSI-TURTLE code creates a new capability for designing certain types of systems. The OASIS Module Builder has been used to create this combination. Several benchmarks have been run to validate the resulting PBO Lab PSI-TURTLE Module and one example has been described.

### ACKNOWLEDGEMENTS

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