A USER FRIENDLY, MODULAR SIMULATION TOOL FOR LASER-ELECTRON INTERACTIONS*

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Abstract

The code RadTrack was developed to accurately model observable beam parameters in real laboratory environments RadTrack is a fast, reliable computational application that can calculate radiation observables in complex interactions between realistic laser and electron beam distributions. The interaction between laser and electron beams is important in processes such as inverse Compton scattering and inverse free electron laser schemes. Modeling these interactions, RadTrack incorporates functions from Synchrotron Radiation Workshop (SRW) with full parsing support to capitalize on well-established radiation generation and propagation code available for start-to-end simulations, while expanding simulated radiation to x-ray regimes [1]. RadTrack is based on the Python environment, which uses a hierarchal module system and possesses built-in data types that will allow further expansions of the code. The code provides an intuitive visualization work canvas that emphasizes the users overall objective.

INTRODUCTION

RadTrack is designed to addresses a number of issues in the accelerator community, with special attention to the radiation properties for direct comparison to available diagnostics. To achieve this, the code emphasizes modularity, breaking down these issues into digestible pieces. The graphical user interface is built on a visualization canvas that easily generates and displays important information. The interface is intuitive for seamless management of start-to-end simulations, which incorporate several codes. The interface allows for simple parallelization for complex, memory demanding calculations. RadTrack was developed as a code that can calculate beam dynamics as well as emitted radiation processes, in a transparent, intuitive manner,.

Complete modelling of a beam from its inception to detection, requires a complicated string of start-to-end studies, employing a concatenation of various function-specific simulations to achieve a high degree of confidence in the final outcome. RadTrack is specifically designed to address start-to-end simulations by seamlessly stitching I/O from various codes and file formats.

The code, RadTrack, was originally developed as an extension to the radiation code QUINDI [2] to calculate the radiative effects of bending beam trajectories. QUINDI was developed for a specific problem and its results benchmarked to experiments at Brookhaven National Laboratory Accelerator Test Facility [3]. RadTrack makes use of QUINDI's particle tracker and radiation field solver, which are based on the Lorentz for and Lienerd-Wiechert potentials, respectively [4]. RadTrack is able to generate laser and electron beam distributions and pass these distributions through an extensive library of optics, magnets and diagnostics, in particular, the use of undulators is important to many laser electron interaction schemes, such as laser heating, laser slicing and sub-femtosecond temporal diagnostics. Figure 1 displays the work flow and modular philosophy of the code; this is advantageous for implementation of the functions, where multiple outputs of codes are parsed as inputs into subsequent codes.

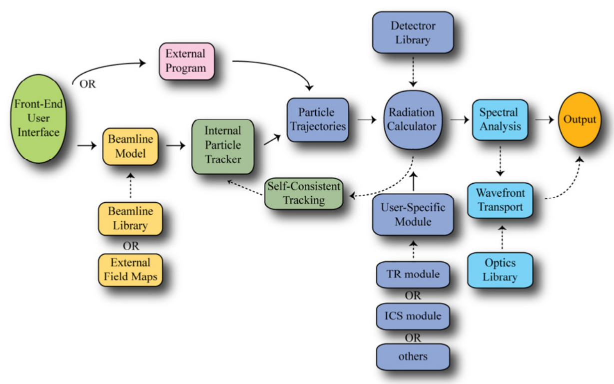

Figure 1: Work flow chart between physics modules, radiation modules, wave front propagator and various libraries.

LASER-ELECTRON INTERACTIONS

The motivation to develop a comprehensive software package that incorporates detailed beam dynamics calculations and radiation interactions has roots in many scientific cases prevalent throughout the advanced accelerator and light communities. Here are some laser electron interactions and their applications:

- The laser-heater is a laser-electron electron interaction in an undulator that increases the beam energy spread in a controllable way to reduce microbunching instability.
- The interaction between a relativistic electron beam and a high power laser induces an undulator-like radiation process that have the ability to produce short wavelength photons [5].
- The interaction between the laser and electron bunch is used to generate a beam energy modulation on the 100 femtosecond scale in storage rings.

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- Recent studies have explored the use of an advanced laser-electron interaction coupled inside an undulator, resonant at the laser wavelength, to achieve sub-femtosecond resolution on the electron beam longitudinal profile [6].
- The recent echo-enabled FEL projects reported from SLAC describe the energy modulation due to a laser in two undulators resonant at the laser frequency or harmonic [7]. The code Genesis can model this FEL experiment [8].

INPUT DATA VISUALIZATION

Laser and Particle Distribution

RadTrack incorporates an instinctive beam distribution panel. Initial beam parameters (used for the source particles) are defined and a 6-dimensional phase space distribution is generated. The user specified inputs include beam moments, correlations, various degrees of noise, and complex modulations or Courant-Snyder parameters. This panel also supports the importing of 6-dimensional particle distributions from external codes, such as ELEGANT [9]. Alteration of beam parameters is handled by textual input or sliders and buttons on the graphical displays, allowing for intuitive creation of particle distributions (such as rescaling of twiss parameters).

Generation of an initial laser distribution is handled in a similar manner, with interface analogues of the particle beam distribution panel. The inputs include wavelength, transverse profile, longitudinal profile, power, beam waist sizes and chirp factor.

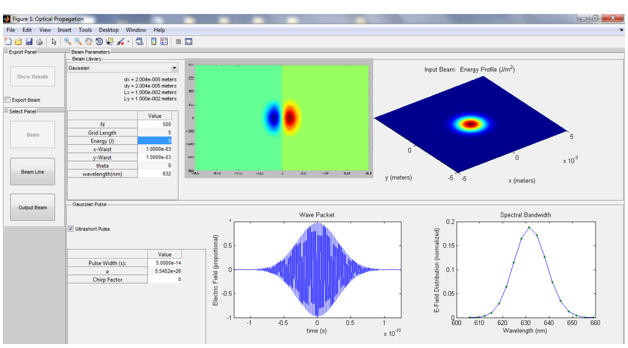

Figure 2: Laser beam generator I/O page from RadTrack, displaying a Gaussian profile, a simple MxN profile and temporal distribution

Beamline Constructor

The definition of the beamline lattice is addressed graphically in RadTrack. Beamline elements, such as drifts, bending magnets, quadrupoles, undulators, etc. are selectable and editable in a text dialog. The reference particle trajectory is calculated and plotted through the displayed beamline for immediate visualization (and error-checking). RadTrack allows for the placement of the detector for radiative processes at arbitrary locations, defined by beam offsets and rotations in the form of Euler angles. This allows for the modelling of bending radiation, such as synchrotron or edge radiation.

Generation of an optical beamline is also graphically generated in RadTrack, with panel analogues of the particle beamline lattice generator.

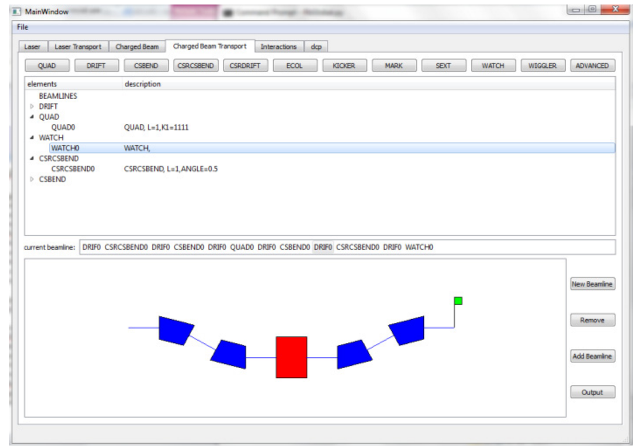

Figure 3: Beamline constructor written in Python with a streamlined interface and dynamic graphical previews.

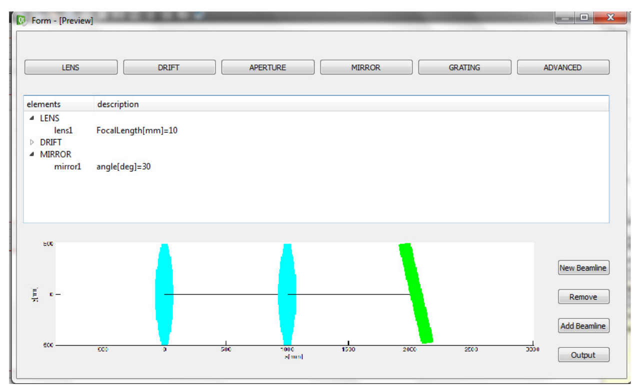

Figure 4: Optical beamline constructor

Originally written in MatLab, RadTrack has been slowly ported over to Python, offering more dynamic and streamlined controls. RadTrack is now equipped with very intuitive drag and drop abilities, where elements created by the user can be dragged from an organized list of available elements and dropped into a beamline. The graphics are also dynamic, as a graphical preview is generated when a user clicks on an element or beamline, and as a user creates a beamline. From there, a user can output a file that can be tuned as an ELEGANT input file or other external codes.

OUTPUT DATA VISUALIZATION

Added to RadTrack is the ability to view and explore data files generated from external code, such as ELEGANT, SRW, QUINDI, plain text files, etc... Parsers were written to identify simulation parameters, display the data in tables. Drop down menus allow the user to select which data sets to graph and RadTrack automatically labels the x and y axis. A toolbar is implemented to be able to zoom in, edit and save graphs. Very large files are broken down into pages and previewed in tables. Convenient functions allow RadTrack to identify filenames and current directories. Some mathematical functionality, such as Fourier transforms and running averages are able to be performed on desired data sets.

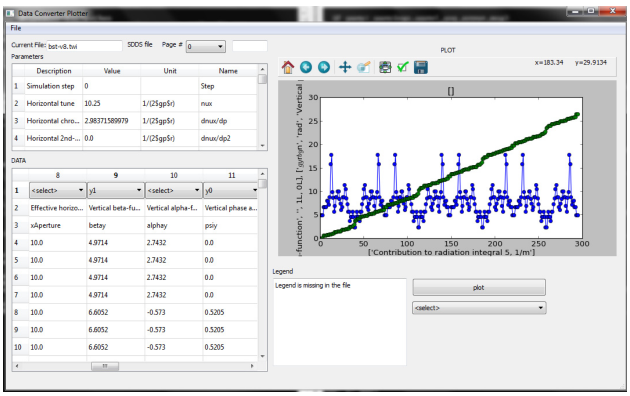

Figure 5: Viewing and plotting data from a self-describing data set (SDDS) [5] file, plotted is the horizontal beta function (blue) and the vertical phase advance (green).

CONCLUSION

RadTrack is a user-friendly tool used for the calculation of beam trajectories and emitted radiation of high brightness beams. The novel user-interface is accessible to a wide range of users and incorporates intuitive features such as the visualization of beam phase space densities and the graphical display of beamline lattice files in real time. It also incorporates a seamless method for start-to-end simulations and parallel extensions via the project management aide. Laser-electron interactions have myriad applications in Free Electron Lasers, ultrafast diagnostics, inverse Compton scattering, laser heating and slicing. One can easily see the convenience of being able to simulate all these processes and devices in a single easy to use interface.

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