RadTrack: A USER-FRIENDLY, MODULAR CODE TO CALCULATE THE EMISSION PROCESSES FROM HIGH-BRIGHTNESS ELECTRON BEAMS*

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Abstract

One of the most important goals of simulations is to accurately model beam parameters and compare results to those obtained from real laboratory diagnostics. Many codes are specialized to either model beam dynamics or emitted radiation. For meaningful physical results, the output of these codes are stitched together in start-to-end fashion. This procedure, which is often employed by simulation experts, is cumbersome, and has wide room for error in data entry or file parsing. This paper describes the development and deployment of RadTrack: a user-friendly code, with start-to-end support of typical accelerator and radiation codes to accurately model laboratory diagnostics.

INTRODUCTION

The code RadTrack was developed to accurately model observable beam parameters in a real laboratory environment. The code emphasizes modularity to address a comprehensive set of problems and an easily navigable user-interface to attract a wide user base. 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 of varying I/O context. The interface allows for simple parallelization for complex, memory demanding calculations. RadTrack was developed as a code that can calculate beam dynamics and emitted radiation processes in a transparent, intuitive manner accessible to most accelerator scientists and students.

RADTRACK CORE

The code RadTrack was first developed as an extension to the radiation code QUINDI [1] to calculate the radiative effects of bending beam trajectories. The code QUINDI was developed for a specific problem and its results have been benchmarked to experiments at the Brookhaven National Laboratory Accelerator Test Facility [2]. RadTrack builds upon the code in a number of ways, while also incorporating other desirable features.

The RadTrack core code is broken down into a number of modular steps. The particle trajectories are calculated using Q-Tracker, an extension to the code QUINDI. Q-Tracker is a simple particle tracker, with trajectories determined by the Lorentz force law, which outputs the 6-dimensional phase space used by RadTrack. The radiation field solver is a modified version of the existing code QUINDI. The radiation emission is calculated using the Lienerd-Wiechert potentials [3]:

$$\vec{E}\left(r,t\right) = \frac{e}{\sqrt{4\pi\epsilon_0}}\left[\frac{\vec{n}-\vec{\beta}}{\gamma^2\left(1-\vec{\beta}\cdot\vec{n}\right)^3 R^2}\right]_{\text{ret}} + \left[\frac{\vec{n}\times\left[\left(\vec{n}-\vec{\beta}\right)\times\dot{\vec{\beta}}\right]}{c\left(1-\vec{\beta}\cdot\vec{n}\right)^3 R}\right]_{\text{ret}}$$

where $\vec{n}$ is the unit vector pointing from the radiation point to an observation point and R is the distance to the observation point. The magnetic field is derived from

$$\vec{B}\left(r,t\right) = \left[\vec{n}\times\vec{E}\left(r,t\right)\right]_{\text{ret}}$$

The fields in the above relations are calculated at the retarded time $t' = t + R(t)/c$.

The RadTrack modular approach separates the functions of particle trajectory calculation and radiation field solving. Figure 1 displays the modular philosophy employed by the code where individual functions are separated to allow for in-depth, comprehensive problem analysis. This is advantageous for implementation of the start-to-end function, where multiple outputs of codes are parsed as inputs into subsequent codes. For example, the user may use particle trajectories from other codes, like TREDI [4], in conjunction with the radiation solver QUINDI or the trajectories from Q-Tracker with another radiation code. Efforts

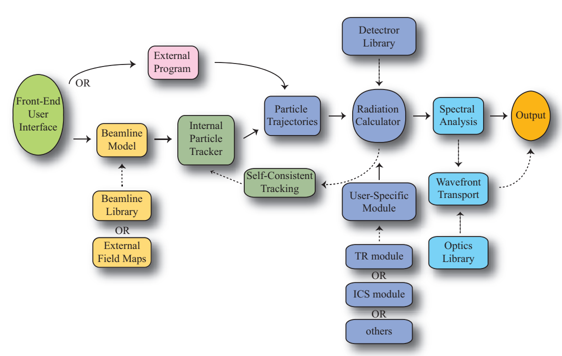

Figure 1: Flow diagram of the RadTrack code design. The ultimate goal is to simulate real laboratory diagnostic observables using the computation tools available to the user (acceleration, radiation, transport, etc.).

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have been directed at including parsers for trajectories from well-established, popular codes like PARMELA [5], ELEGANT [6], and TREDI.

User Interface

The RadTrack user interface is also modular, separated into panels with distinct features. The panels are intuitively designed to contribute to a smooth workflow.

Particle Distribution RadTrack incorporates a useful 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 the Courant-Snyder parameters. This panel also supports the importing of 6-dimensional particle distributions from some external codes. The built-in parser also offers rudimentary distribution analysis and graphical representations of the beam. Alteration of the beam parameters is handled by textual input or by sliders and buttons on the graphical display of the beam, allowing a very intuitive method of creating unique and specific particle distributions (such as rescaling Twiss parameters).

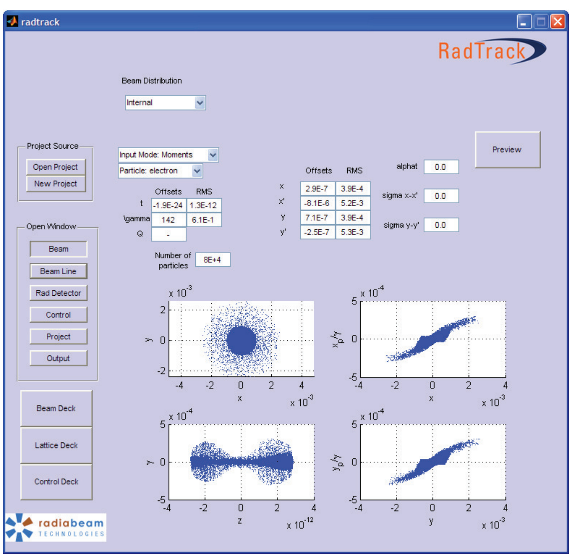

Figure 2: Screenshot of the beam distribution panel in RadTrack displaying transverse profiles, and transverse and longitudinal correlations of a user generated source beam.

RadTrack supports a number of particle distribution sets. Gaussian beam distributions are generated by a normalized Box-Muller transformation [7] of a uniform distribution. The final distribution is formed by dialation, rotation and shearing of the distribution. Other distributions (such as waterbag, K-V, boxcar, etc.) are also supported, however in a basic, limited fashion. The quiet start [8] has been investigated and has recently been shown to be of great importance because it reduces artificial beam microbunching that leads to overestimates of the beam emittance and quality.

Beamline Visualization Aide The definition of the beamline lattice is addressed graphically in RadTrack. Beamline elements, such as drifts, bending magnets, and focusing magnets, are selectable and editable via a palette. The reference particle trajectory is calculated and plotted through the displayed beamline for straight-line visualization. The graphical output of this aide is a beamline of block shapes representing different magnetic elements while the textual output is tab-delimited text file (input deck) of the beamline lattice for use in Q-Tracker. Parsers for other codes are also available.

RadTrack allows for the placement of the detector for radiative processes at arbitrary locations, defined by beam offsets and rotations in the from of Euler angles. This allows for the straightforward modeling of bending radiation, such as synchrotron or edge radiation, as the user may lock the detector plane tangential to the reference trajectory. Modeling specific diagnostics, such as those for other types of radiation sources (inlcuding Compton, THz, etc.) requires using this visually descriptive method for detector placement (Figure 3).

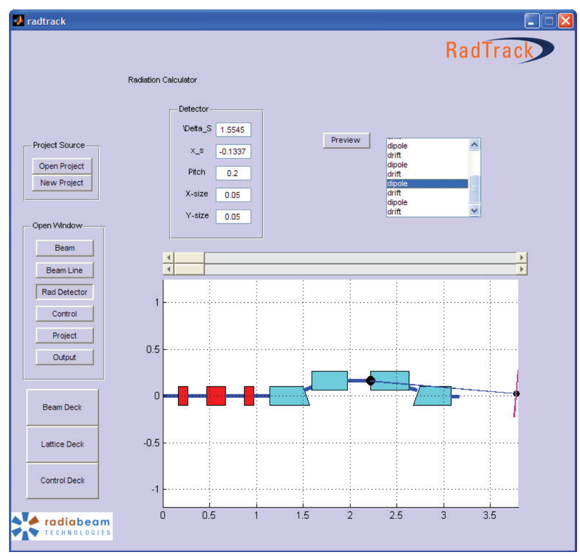

Figure 3: Screenshot of the user interface displaying the beamline constructor with a radiation detection screen. This example of the BNL ATF chicane compressor was created to benchmark the code to laboratory data.

Parallel version Simulation project management is built directly into the RadTrack framework to aid in extending the computational capabilities from a single processor to a multi-node computing cluster. The management of files allows for multiple runs based on previous input data sets and outputs in a variety of formats.

The ability to run single particle calculations and highly detailed design studies, requiring the use of a cluster, is accomplished using a single interface. Also, start-to-end simulations are executed, and I/O file parsing is accomplished, through the project manager. This feature is useful because the user will experience a consistent, undisturbed workflow while the code handles the necessary parsing and I/O interplay between the codes. Additionally, the file management of the various output files of each code are easily accessible, stored and organized by the software. The parallel version addresses the need to simulate large number of particle sets for complex problems (such as microbunching, and coherent transition radiation at optical wavelengths).

Post-processor The RadTrack post-processor was inspired by the demand to retrieve useful information for the simulation in a timely fashion. It displays spectral information using simple, built-in mathematical function tools. This gives the user valuable information on the validity of the performed run before further, extensive analysis is completed. It is envisioned that this unit will be incorporated into a real laboratory control room to provide near real-time beam information to be used by the experimenter for data taking or for use in a feedback loop to ensure high quality beam control.

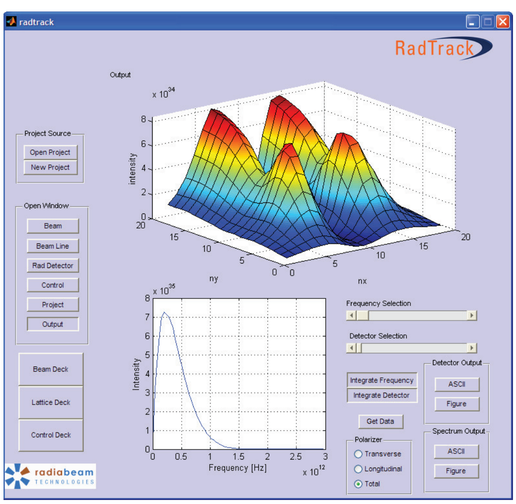

Figure 4: Screenshot of the post-processor unit displaying a calculation performed for the BNL ATF experiment..

CONCLUSIONS

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.

Due to its modular nature, new module development to solve specific radiation problems is straightforward to incorporate. Efforts in radiation transport and Inverse Compton Scattering solvers are underway. Improvements in space charge and coherent synchrotron radiation effects are also being investigated to enhance the capabilities of RadTrack.

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