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Simulating electron beams in RF cavities with beam loading

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High-brightness electron photoinjectors and electron linacs are fundamental to many advanced accelerator concepts and associated applications (see e.g., Ref. [1] and references therein). The industrial, medical and homeland security markets for low-to-moderate energy electron linacs are growing rapidly. To meet the design challenges for these divergent applications, with modest software development resources, a simulation code must meet the following requirements: a reduced-model algorithm that includes beam loading in rf cavities; phase space conserving algorithms; a single-source implementation that executes efficiently on many CPUs, on one or more GPUs, and on heterogeneous supercomputing architectures; as well as easy benchmarking with high-fidelity community codes.
We present recent work with the open source Hellweg code [2-4], which is routinely used to design TW electron linacs, showing 1000x speedup as compared to CST Particle Studio. We plan to refactor Hellweg's C++ source code to make effective use of the AMReX framework [5,6], joining an ecosystem of massively parallel accelerator physics codes under development at Berkeley Lab. The reduced model algorithms in Hellweg will play an important role, in concert with other more high-fidelity PIC codes.
We will describe the underlying algorithms in Hellweg, as well as recent and ongoing generalizations. Recent work on traveling wave linac simulation and design will be presented. Time will also be devoted to a discussion of future plans, which include treatment of Touschek scattering, thermionic and photocathode electron guns, and a modified algorithm to conserve phase space.

[1] F. Stephan et al. "High Brightness Photo Injectors for Brilliant Light Sources," Synchrotron Light Sources and Free-Electron Lasers (2020). Ed. by E. Jaeschke et al.
[2] S. V. Kutsaev et al. "Generalized 3D beam dynamics model for industrial traveling wave linacs design and simulations," NIM A 906 (2018), p. 127.
[3] Y. Eidelman et al. "Ellipsoid space charge model for electron beam dynamics simulations," Phys. Part. Nucl. 52 (2021), p. 477.
[4] The open source Hellweg repository, https://github.com/radiasoft/rslinac
[5] W. Zhang et al. "AMReX: a framework for block-structured adaptive mesh refinement," Journal of Open Source Software 4 (2019), p. 1370.
[6] The open source AMReX repository, https://github.com/AMReX-Codes/amrex

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