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Comparison of Eulerian, Lagrangian and Semi-Lagrangian Simulations of Phase-Space Density Evolution

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Good understanding of the underlying beam dynamics is mandatory for the successful design and operation of Free-Electron Lasers. In particular, it is important that all physically relevant collective effects are adequately represented in simulation codes so that their influence on the phase-space evolution of the bunch can be calculated with sufficient accuracy at all relevant length scales. Besides coherent collective effects such as space charge or coherent radiative interaction also incoherent effects such as intra-beam scattering are suspected to have a significant impact on the efficacy of sophisticated lasing techniques.
Most of the well-known and widely-used beam dynamics codes employ the Lagrangian approach, in which the particle bunch is represented by discrete points in phase-space and track the solutions of their equations of motion. In contrast to that, in the Eulerian and semi-Lagrangian approach, the bunch is described by a numerical representation of its phase-space density function.
This contribution discusses the working principles of the three classes of simulation methods Lagrangian, Eulerian, and semi-Lagrangian and highlights their respective advantages and short-comings, when applied to the simulation of collective beam dynamics in FELs.

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