Convolution-Based Solvers for Modeling Space Charge and Radiation: OpenSC, CSR3D, LW3D

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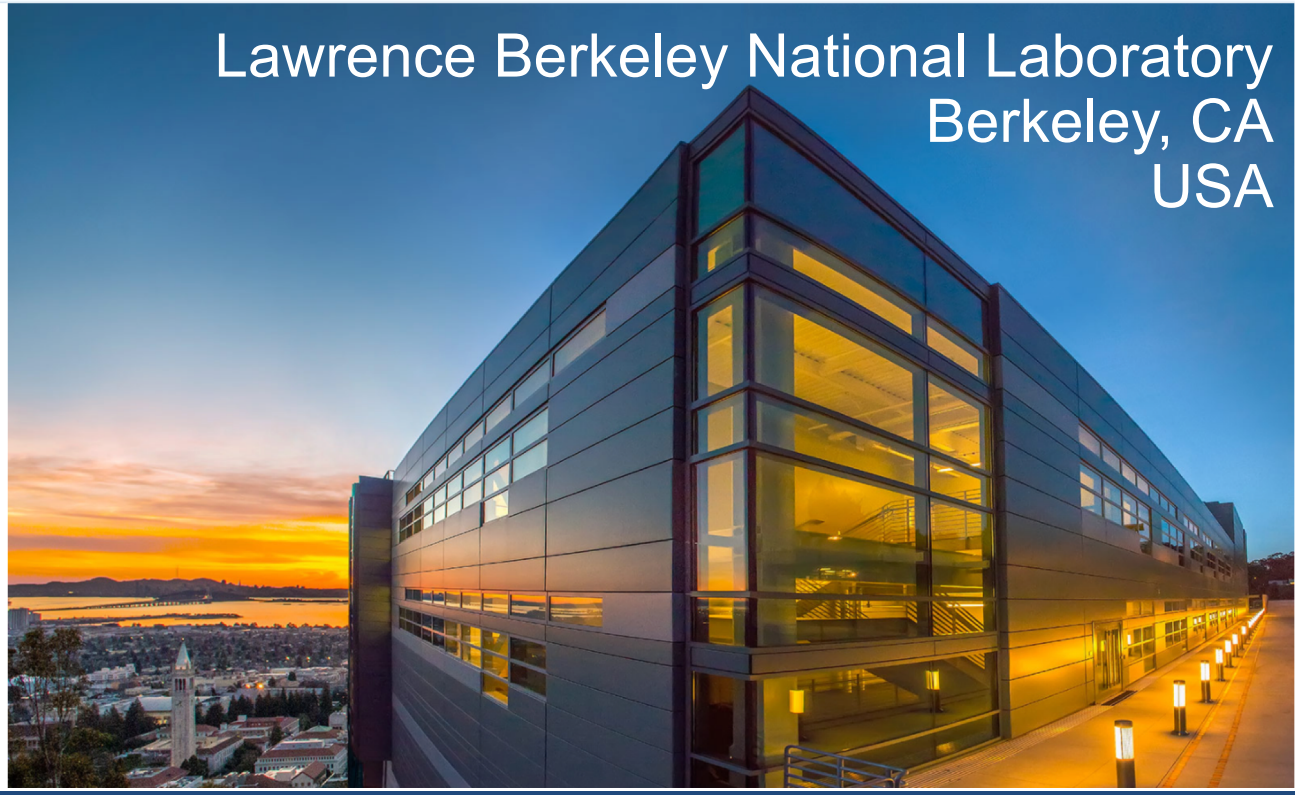
1st

BLAST
BERKELEY LAB ACCELERATOR SIMULATION TOOLKIT

workshop



Outline

- Introduction
- OpenSC
- CSR3D/LW3D

Overview

- Software for calculating
  - 3D space-charge fields (OpenSC)
  - 3D space-charge and radiation (CSR3D/LW3D)
- OpenSC is a library of 3D Poisson solvers for use in accelerator codes
  - Originally developed for use in Warp
  - Adopted and modified for use in Bmad
- CSR3D was originally written to compute CSR fields
  - Uses a Lienard-Wiechert approach
- LW3D is a prototype code that extends CSR3D to self-consistent modeling

Review of Convolution-Based Space-Charge Method

- Beam dynamics codes with Poisson solvers are widely used in the accelerator community for rf accelerator design with space charge
- Many problems involving space-charge can be treated by a model that assumes
  - simple boundary conditions
  - electrostatic in the beam frame
- Convolution-based approach solves for the potential (or fields) by calculating

$$\int \rho(\vec{x}')\vec{G}(\vec{x}-\vec{x}')\,d\vec{x}'$$

Discretization of the Green Function

- Simplest discretization simply uses G at values of grid-point separation,

$$\int \rho(\vec{x}')\vec{G}(\vec{x}-\vec{x}')d\vec{x}' \Rightarrow \sum \rho_j G_{i-j}$$

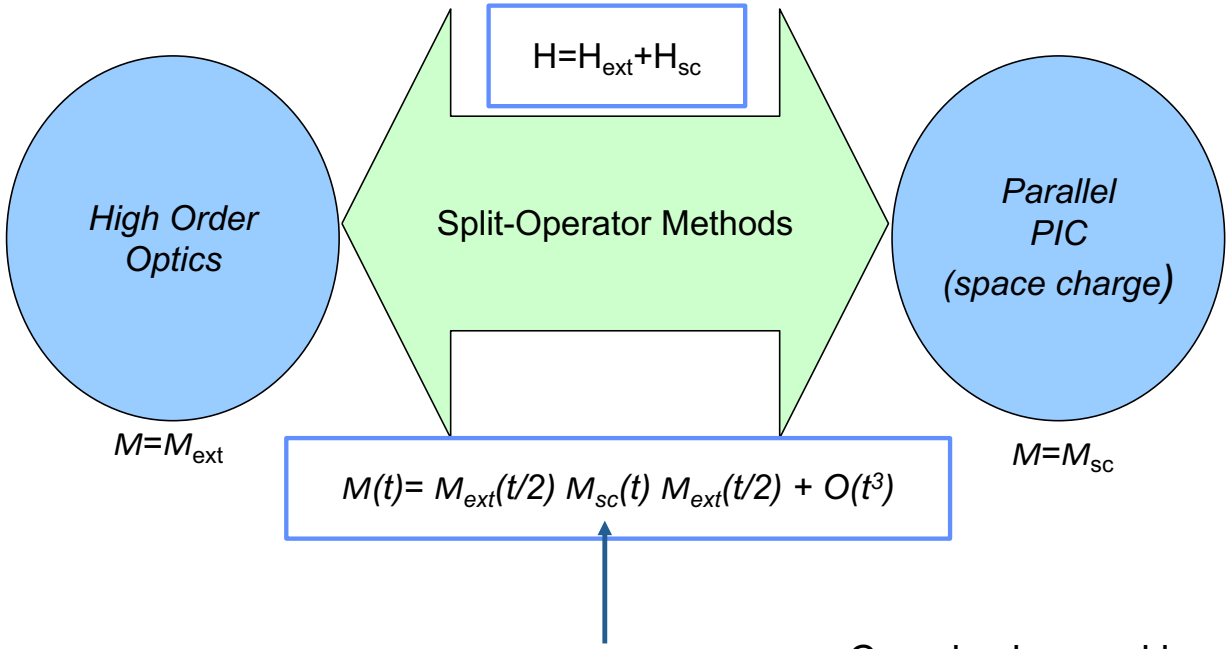
- Use FFTs to perform the discrete convolution
  - turns $O(N^2)$ problem into $O(N \log N)$
  - This is a mathematical trick (not a spectral algorithm)
- Having found the potential, compute the E field
  - Or could perform 3 convolutions to compute E directly
- ES PIC codes normally compute B assuming the beam is mainly unidirectional (only A_z)

Better: Use an Integrated Green Function (IGF)

- Simplest discretization can produce erroneous results when grid aspect ratio is large
  - Issue is not really aspect ratio; the root cause involves the variation of G within a grid cell
  - Results can be wrong but not garbage; not obvious that the code is wrong
- Use of an Integrated Green function (IGF) solves the problem
  - Robust solver, little sensitivity to grid aspect ratio
  - Accuracy depends on choosing a fine enough grid to resolve ρ

Many people want to put 3D space-charge in their code. To avoid people "reinventing the wheel" we developed OpenBC

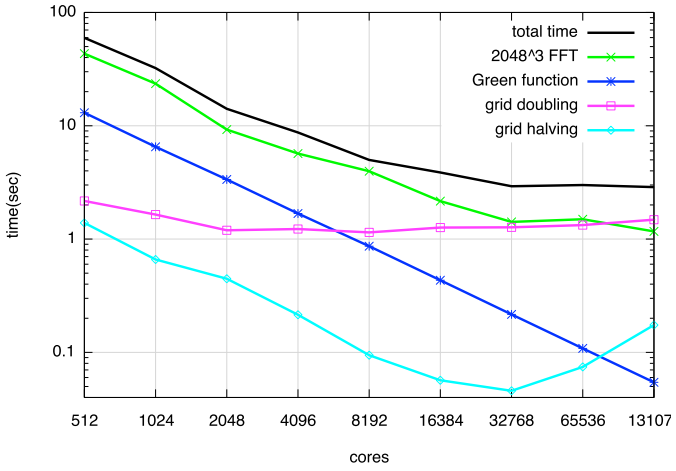
- Parallel, reusable, convolution-based, 3D space-charge library
- Currently supports
  - Free-space boundary conditions
  - Rectangular waveguide boundary conditions
- Parallel 3D FFT uses the package by S. Plimpton, SNL
- Build system, OpenMP support, other enhancements by C. Mayes (SLAC)
- Current version of OpenBC is on github; will be incorporated into Picsar



Can also be used in a Lorentz-force code but need to be aware of timescales of various phenomena in impact on performance

OpenBC uses the Parallel 3D FFT package by S. Plimpton. Tested on up to 131K cores of Edison at NERSC

2048^3



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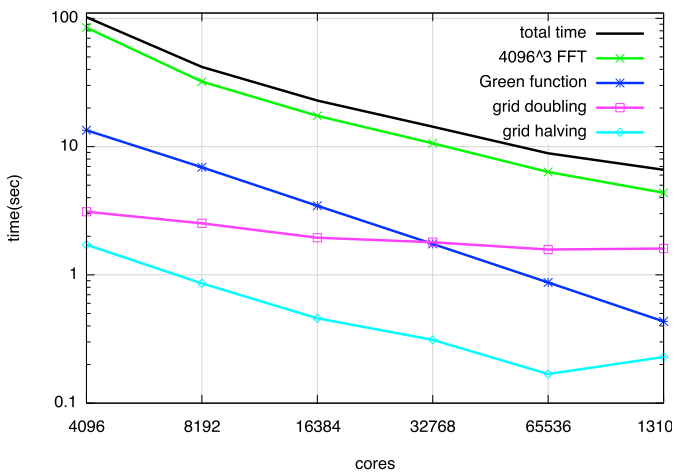

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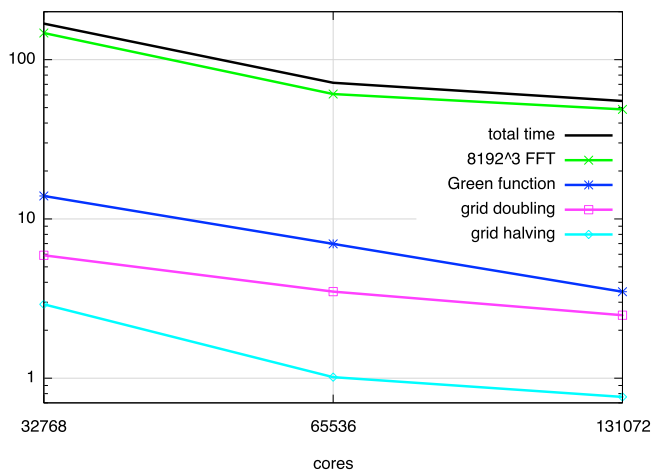
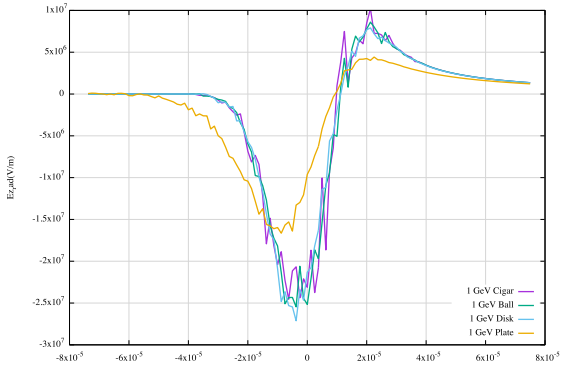


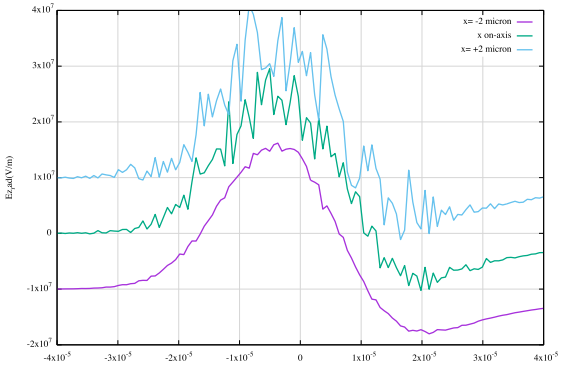
CSR3D: A massively parallel code for studying 3D CSR effects

- Originally developed by R. Ryne in collab. with B. Carlsten, C. Mitchell, and J. Qiang
- Two versions: (1) Point-to-grid, and (2) Convolution-based
- Convolution-based version uses a Lienard-Wiechert Particle-Mesh (LWPM) method
- Has been to study aspects of CSR, especially 3D effects and stochastic effects, that would be difficult or impossible to simulate with other codes
- References:
  - R. Ryne et al., "Large Scale Simulation of Synchrotron Radiation using a Lienard-Wiechert Approach," Proc IPAC 2012
  - R. Ryne et al., "Using a Lienard-Wiechert Solver to Study Coherent Synchrotron Radiation Effects," Proc FEL2013
- In 2017 used by B. Garcia (SLAC) for comparison with an analytical model of CSR
  - B. Garcia, T. Raubenheimer, and R. Ryne, "Stochastic Effects from Classical 3D Synchrotron Radiation," Proc FEL2017
- Marinelli et al plan to use to study a new method for eSASE
- Interest in 3D CSR modeling is picking up – discussion at IPAC18; Slack channel…

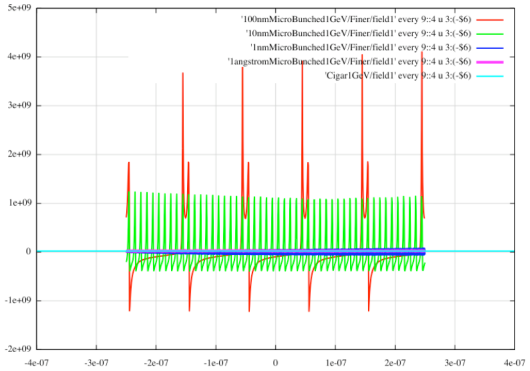
A sample of CSR3D results



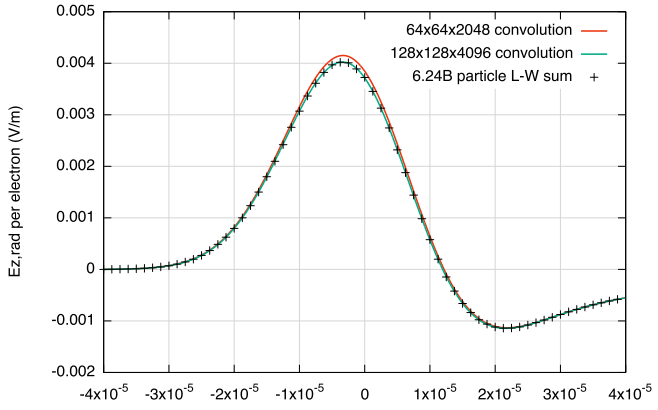
Limits of the 1D CSR model



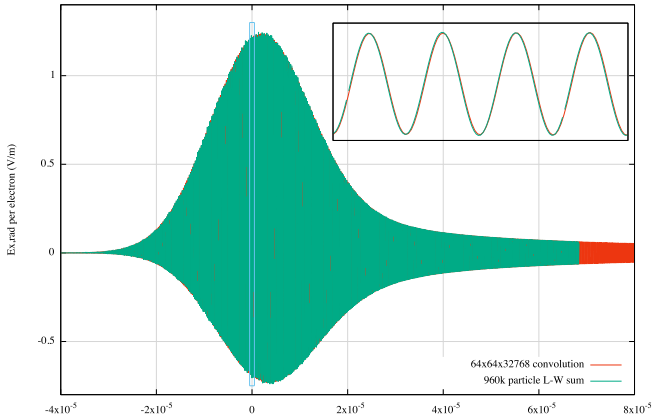
Spatial dependence of stochastic field



Microbunching field enhancement in an undulator



3D convolution vs LW sum: Steady-state dipole radiation



3D convolution vs LW sum: Undulator radiation

CSR3D Status

- CSR3D can be run at NERSC
- It only computes fields, it's not a self-consistent code

- This was my first attempt to model 3D CSR
- The coding is not pretty
- Some have looked at the source code, with unfortunate results…

The LW3D code

- CSR3D is being modified to be easier to maintain and to enhance its functionality for modeling realistic problems
- The new code is called LW3D in recognition of the fact that it is a Lienard-Wiechert code, not just a code for CSR
- LW3D will be capable of self-consistent modeling
- A prototype exists and is being debugged
- In the meantime CSR3D is available at NERSC

Acknowledgements

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- US DOE Office of Science, Office of BES
- LANL LDRD (2012)
- NERSC resources have been *essential* to this effort