Development of a Virtual Detector for the Advanced Particle Accelerator Modeling Code *WarpX*

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ABSTRACT

A current promising field of research, laser-driven ion acceleration has the potential to reduce the size, cost, and energy consumption of particle accelerators by orders of magnitude.

To better refine the instrumentation, we have developed a virtual diagnostic to measure electromagnetic radiation such as radiation produced from scattered and transmitted laser beams which has been implemented into WarpX, an advanced Particle-in-Cell code that simulates laser-driven particle acceleration. This "FieldProbe" diagnostic provides field measurements and is parallelized using the Message Passing Interface (MPI) and can thus run on High Performance Computing systems such as the NERSC Cori cluster.

BACKGROUND INFO

Conventional RF Accelerators are costly and massive, requiring big financial investment.

A promising research field for compact particle acceleration is laser-driven ion acceleration, using a ultrahigh-power (PW), short (~30 fs) laser pulses to create a plasma that facilitates ion acceleration.

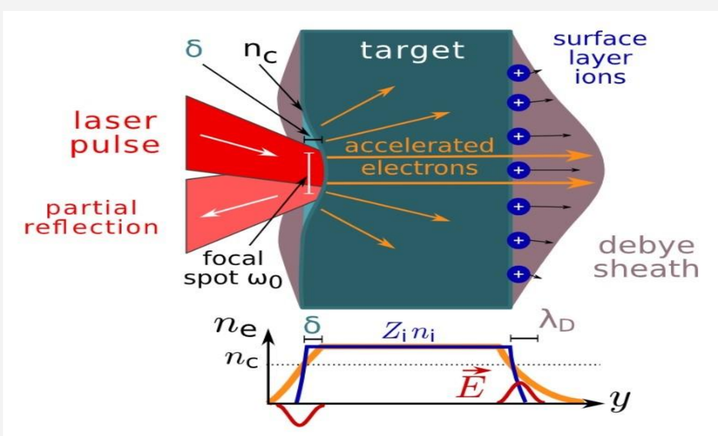

FIG 1. Basics of laser-ion acceleration. Laser energy is absorbed by electrons which separate from ions. The resulting EM field facilities acceleration. Ref. [1]

- accelerator length: meters -> microns
- to control this ultra-small acceleration, testing and modeling is required

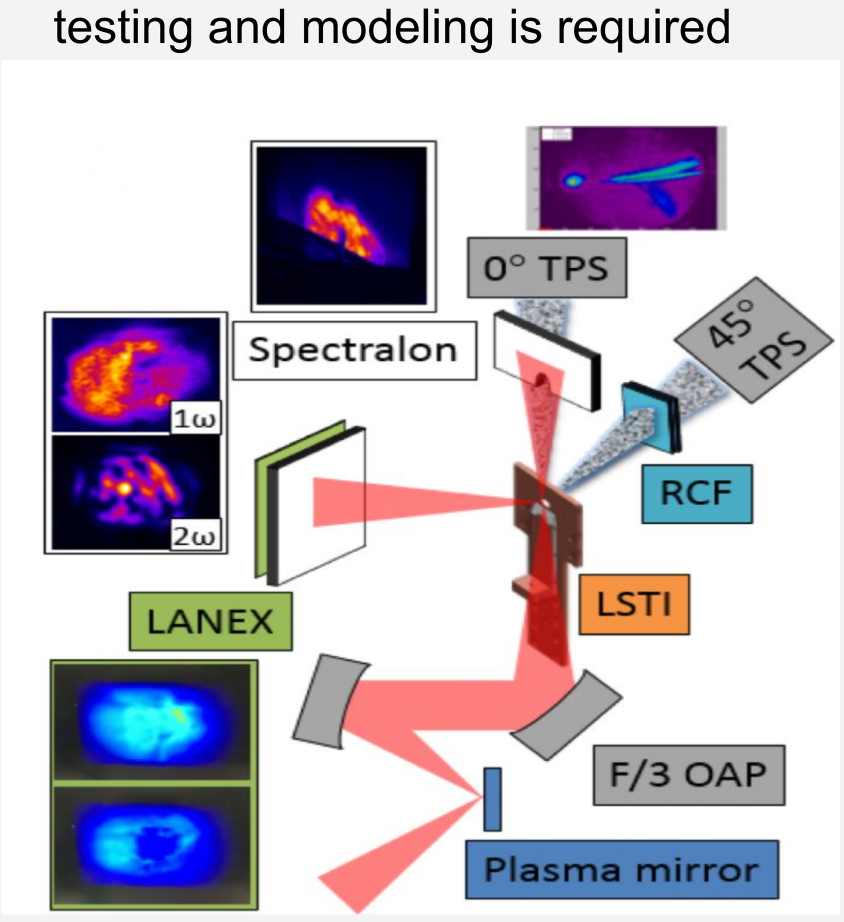

FIG 2. Experimental setup of laser-ion acceleration. The laser pulse interacts with the plasma at LSTI, causing ions to be accelerated. Energy detectors (TPS) are placed to measure accelerated ions. Ref. [2]

PIC Method

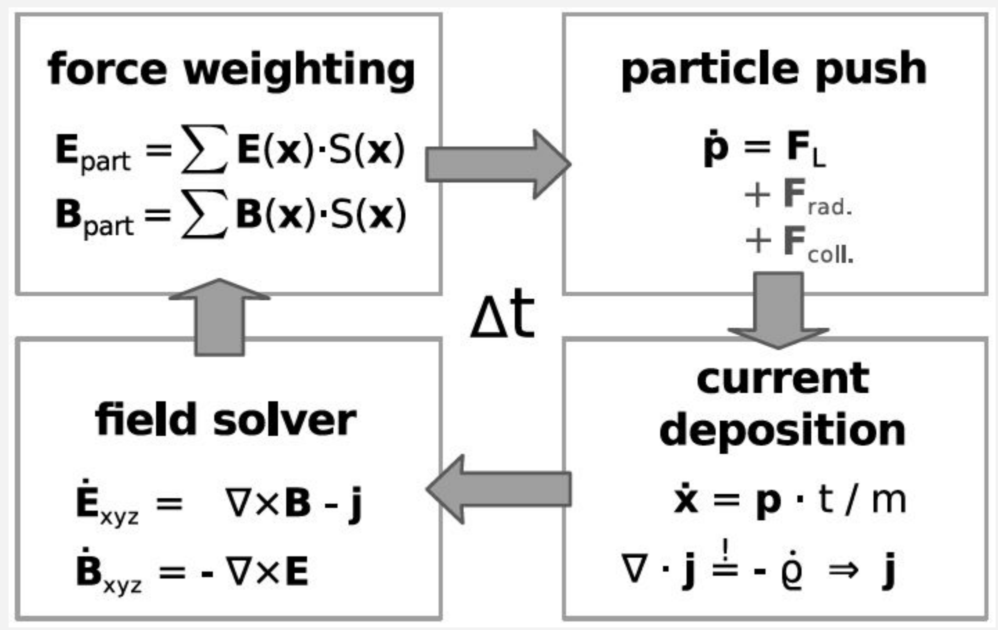

FIG 3. Electromagnetic Particle-in-Cell method used in WarpX to model laser-ion acceleration. The first two Maxwell's equations are ensured by charge-conserving solvers and self-consistent initial & boundary conditions. Ref. [1]

GPU and Parallel Computing

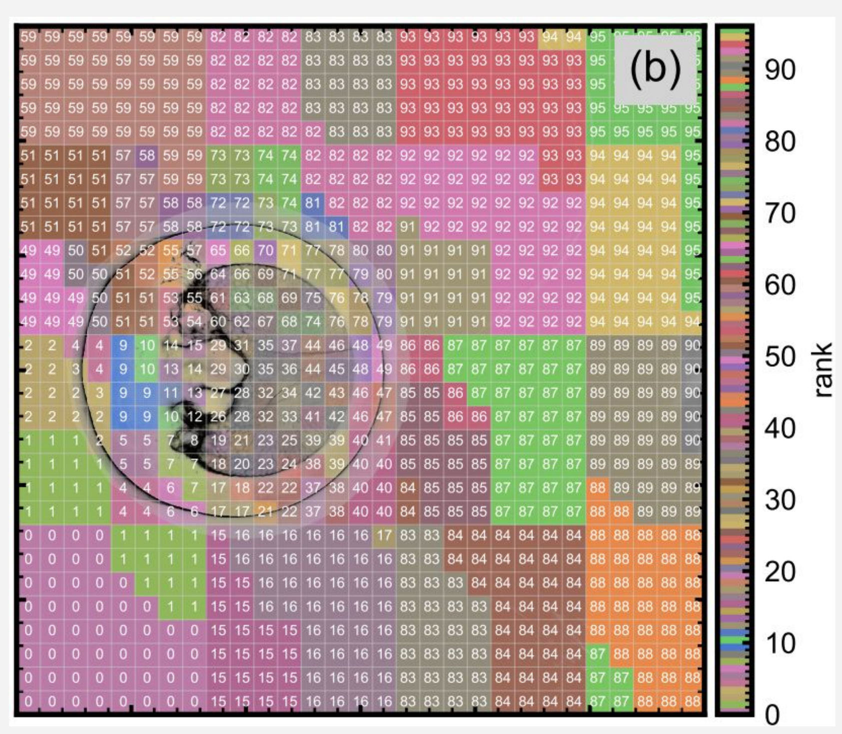

FIG 4. Domain decomposition for GPU for High Performance Computing clusters. WarpX uses a Cartesian, block-structured mesh. Ref. [3]

Simulation space is divided into regions, which are assigned to individual computing ranks. Generally, GPUs are assigned to ranks whereas CPUs manage assigning ranks and communication. Areas with high processing requirements are assigned more GPUs.

AMReX facilitates WarpX's parallel communication and domain decomposition.

A Virtual Detector Twin

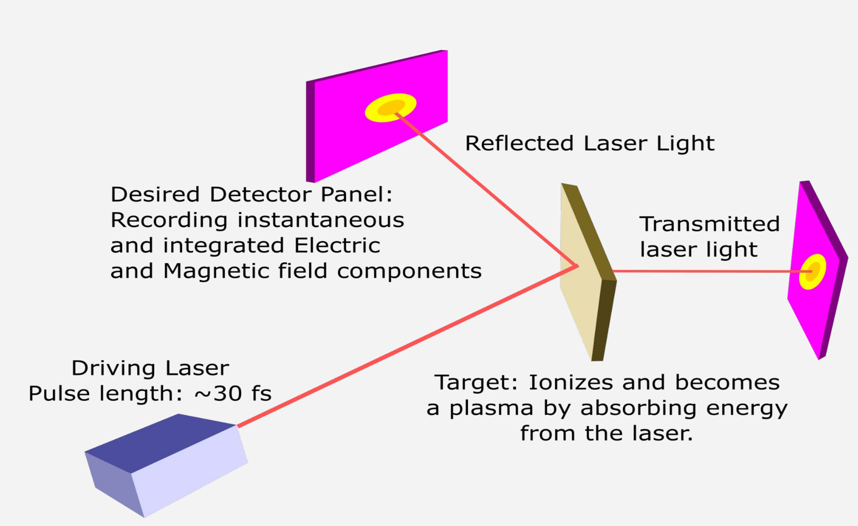

FIG 5. Virtual detector setup. The position, shape, and size of the detector is completely adjustable to cover points, lines, and planes.

Design Chart

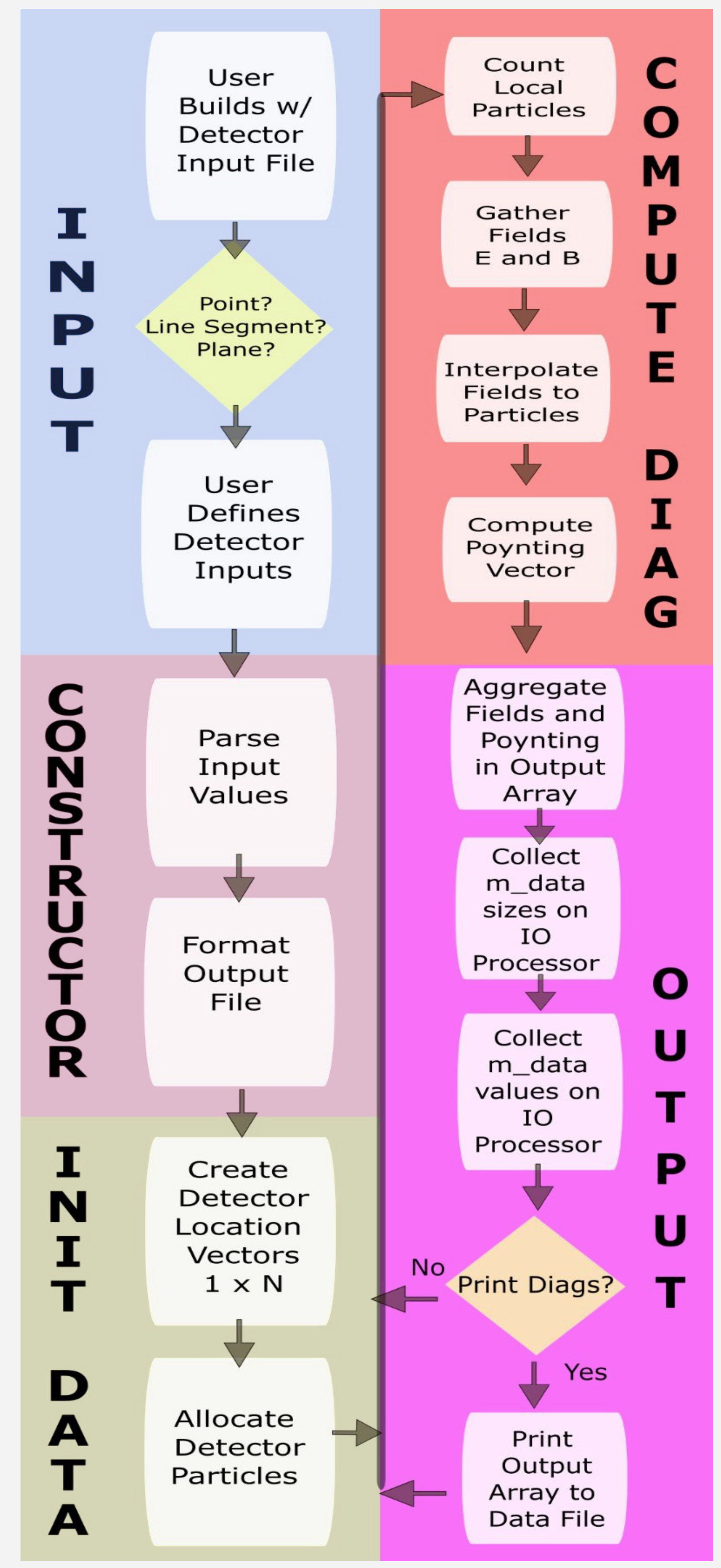

FIG 6. FieldProbe implementation logic. The left half executes once while the right half executes during every step of the PIC loop.

Implementation Details

- **Particle Container** class created to store SoA and AoS probe data
- For *instantaneous* values, run diagnostic only during print-to-file steps
- For *integrated* values, run diagnostic every step, print on print-to-file steps
- **On each compute rank:**
  - loop over mesh-refinement levels (atm. 1)
  - iterate over spatial boxes of particle tiles
  - *interpolate field data to particle positions*
    - can run on CPUs and GPUs
  - MPI communication
- Can record ***points*** (single particle), 1D ***line*** (strip of particles), and 2d ***plane*** (thin mesh of particles) detectors
- Developed as open source for ease of access!

ECP-WarpX/WarpX

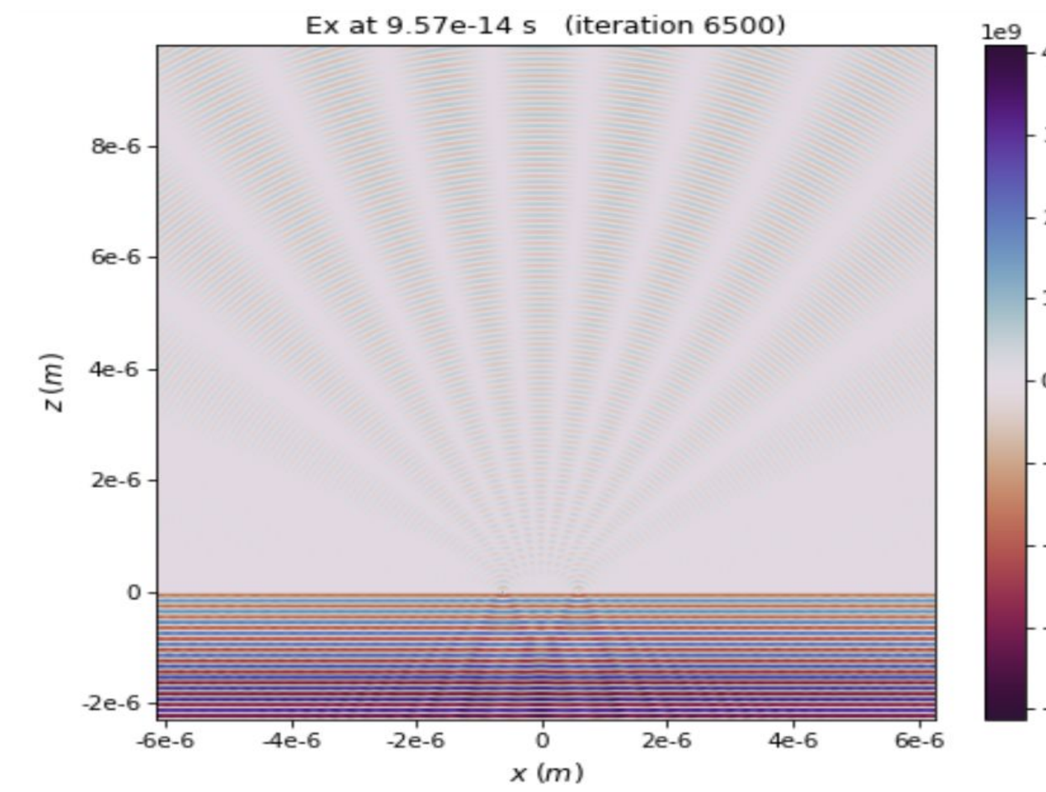

FIG 7. Scattering of a linearly polarized, plane, electromagnetic wave on an embedded boundary double slit (not shown). Visualization of the x component of the electric field created with openPMD-viewer.

Benchmarks

Far Field: $z > \frac{2D^2}{\lambda}$

- Z = distance between detector and antenna (double slit)
- D = diameter of antenna (slit width + slit distance)
- λ = wavelength

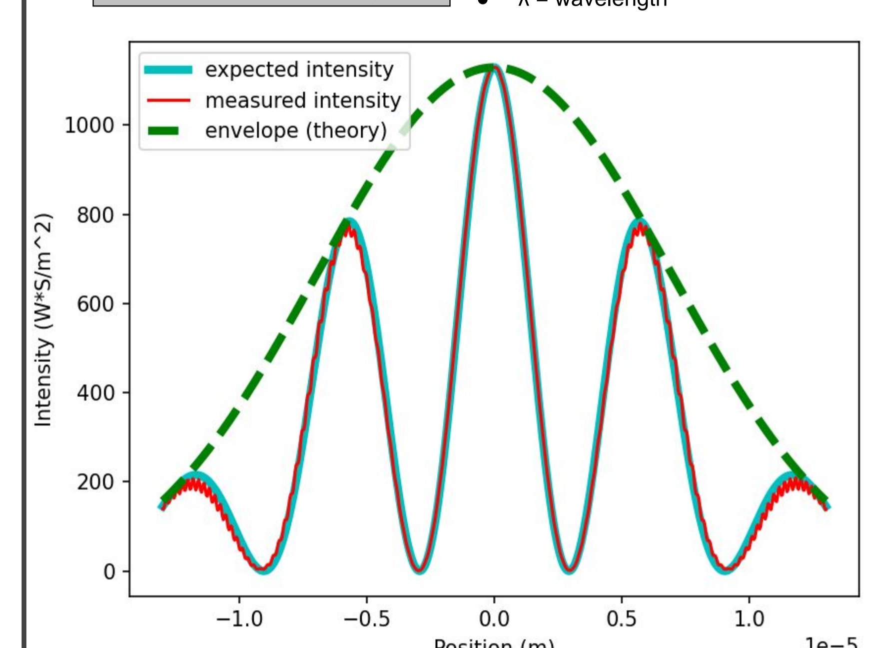

FIG 8. (left) Final time step graph of measured *integrated* Poynting vector magnitude vs. theory.

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