LCODE 3D: a free quasistatic plasma wakefield acceleration code

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What LCODE 3D is about

LCODE is a leading code for quasistatic simulation of particle beam-driven plasma wakefield acceleration, originally developed by Dr. Konstantin Lotov. It excels at simulating long-term evolution of long particle beams.
LCODE 3D is a recent LCODE rewrite for 3D geometry.
It aims to offer the same key strengths:

- quasistatic kinetic plasma response calculation,
- fully relativistic beam model,
- efficient parallel calculation of beam evolution,
- aggressive use of substepping,
- outstanding numerical stability (see below) and
- inherently simple and straightforward underlying models and equations,

while sacrificing as little performance as possible.

Additionally, LCODE 3D aims to add several more software-specific qualities to the mix, such as:

- open-source license (AGPLv3) and development model
- modern agile implementation language (Python/Cython)
- aspect-oriented architecture
- integration into other software as a library
- adoption of HDF5 as an input, output and internal format

LCODE is getting a 3D rewrite

An open-source 3D rewrite if LCODE is in the works, striving to match and surpass its 2D predecessor.

Numerical stability

Unfortunately, as for the current revision, LCODE 3D plasma-field solver suffers from a numerical instability in ξ coordinate (the direction along the beam). This imposes a limit on the driver length, as the plasma response is adequately simulated for several tens of Langmuir oscillation periods from the beam's head. Strong fields and non-linear interaction modes may exacerbate the instability, making the limitation even more daunting.
While the instability can be partially suppressed by using a sparse plasma workaround, LCODE 3D still struggles with long simulation windows, such as AWAKE's former 12 cm or proposed 6 cm.

Example 3D simulation compared with 2D

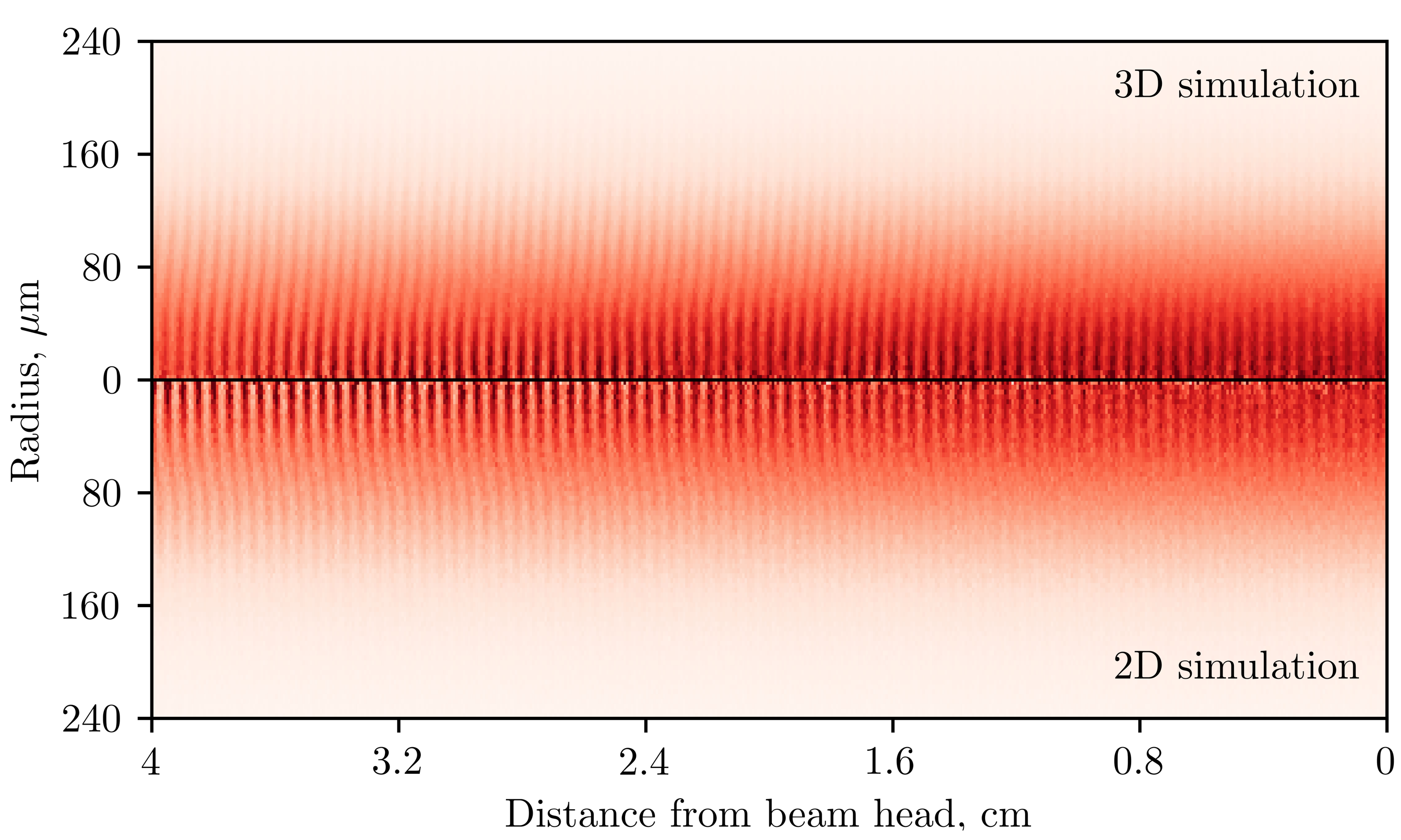

Figure 1: Radial charge density portraits of a proton beam, demonstrating SMI in the AWAKE 2014 baseline simulation, pictured after passing 1.6 m of plasma. Self-modulation is visible in both cases, the differences accumulate towards the beam tail. The simulation was restricted to the first third of the beam (4 cm) due to the aforementioned numerical instability,

LCODE 3D still cannot simulate the AWAKE beam

Extra long simulation windows are not supported yet.

Sparse plasma interpolation vs. grid noise

One of the factors contributing to the longitudinal instability was identified as transverse field noise with a transverse grid period. This is a purely numerical problem, which manifests itself as a tendency of plasma particles to group into cell-sized patterns, introducing high-frequency noise to the charge density profile and hindering solver precision and stability. The problem accumulates in xi and limits the maximum length of the simulation window.
Our workaround is to make the transverse cell size lower than the distance between the plasma macroparticles (or, if you wish, to start with a very sparse initial plasma distribution). Using, e.g., $\frac{1}{4}$ or $\frac{1}{9}$ macroparticles per cell allows us to circumvent the instability growth: the transverse noise stops making neighboring particles stick together, as they now reside in different periods.

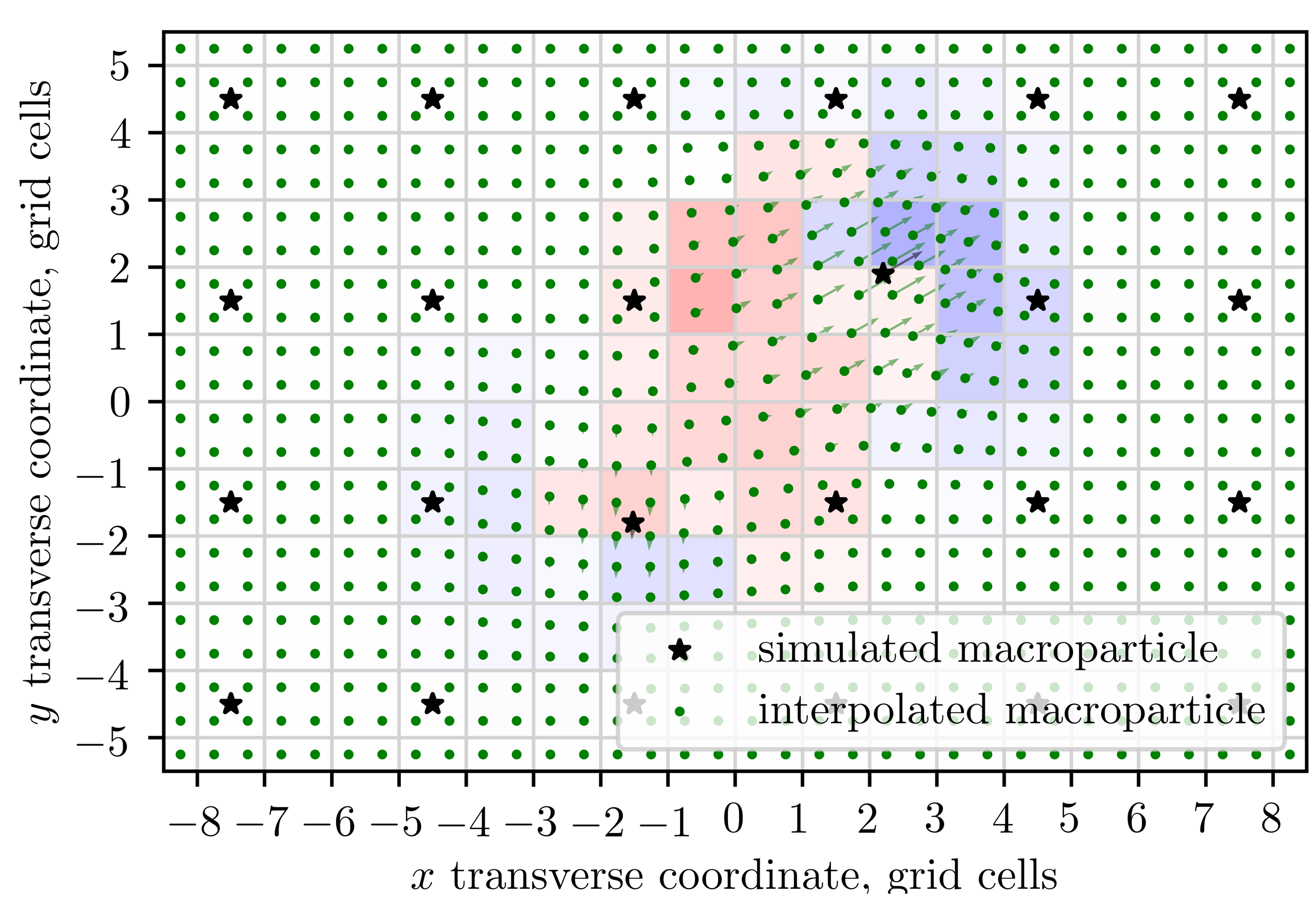

Figure 2: Example: simulated plasma electron macroparticles (stars) are interpolated onto a fine particle grid (green circles) as an intermediate step of depositing sparse plasma (stars) charge density (cell color) onto the cell grid (light gray squares).

To derive the plasma density, one has to smooth it across several inter-particle cells, for example by interpolating the coarse plasma grid onto an finer grid of particles before applying a generic deposition algorithm. Reinterpolation based on changing particle locations is prohibitively resource-consuming, while interpolation based on the initial distribution has limited applicability in non-linear interaction regimes. A more complex adaptive approach may be beneficial.

Other future plans

- 3D laser driver interaction and evolution.
- Plasma particles trapping.
- More modularity, live diagnostics, configuration flexibility.
- A stripped-down version targeting simplicity, comprehensibility and agility.

Contact Information

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