LASY: LAser manipulations made eaSY

An open-source Python library to facilitate the use of realistic laser profiles in simulations

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Motivation

- **Realistic laser profiles** are key for realistic simulations of laser-plasma interaction [1].
- Start-to-end workflows require interfacing simulation tools with **different laser representations**.
- **Laser manipulations** (conversions, propagation, etc.) are required and error-prone.

➢ LASY simplifies these workflows with **modern programming methods** (Open-source, Python, CI/CD, data standards).

Experimental data
3D data (e.g. INSIGHT [2]) or separate transverse + spectral

Simulation output
Electric field or vector potential separate transverse + spectral

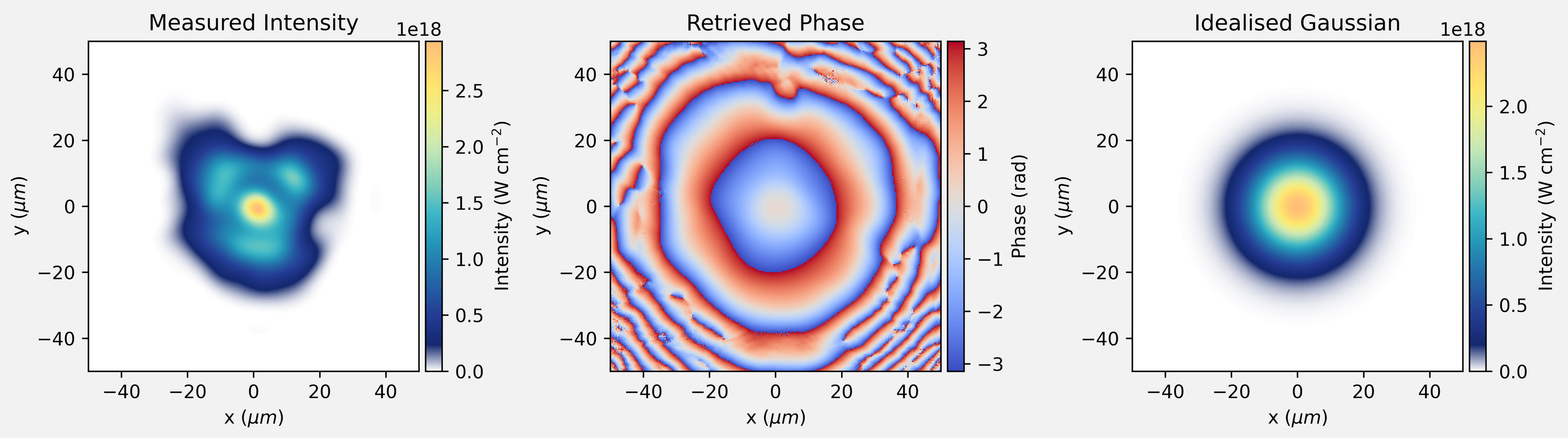
Analytic profiles from LASY
Gaussian, Hermite-Gauss, Laguerre-Gauss

LASY
- Convert electric field ↔ vector potential
- Convert full field ↔ laser envelope
- Construct 2D cylindrical/3D Cartesian profile
- Filter/smooth data
- Propagate in vacuum to desired location
- Write to file

→ openPMD

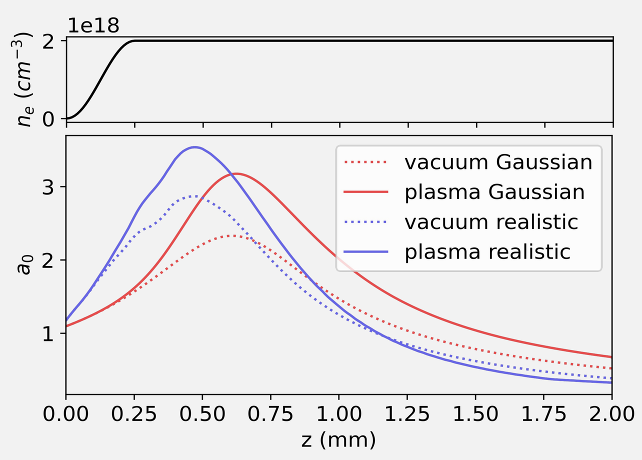
Simulation/post-processing

From measurement to simulation



Starting from measured temporal and transverse profile

➢ Reconstruct amplitude and phase using **Gerchberg-Saxton [3]** algorithm
➢ Combine longitudinal and transverse profiles on a 3D grid
➢ Propagate the pulse
➢ Write the pulse to openPMD file



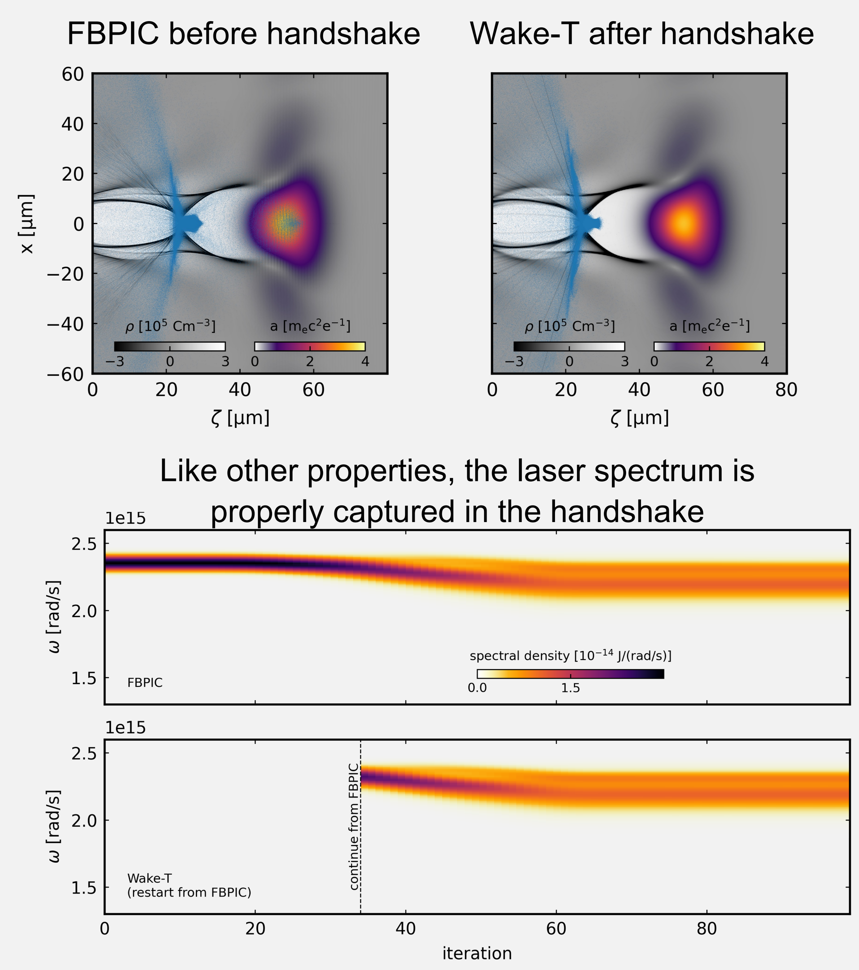
Read the file (here in HiPACE++ [4]) for a realistic plasma acceleration simulation

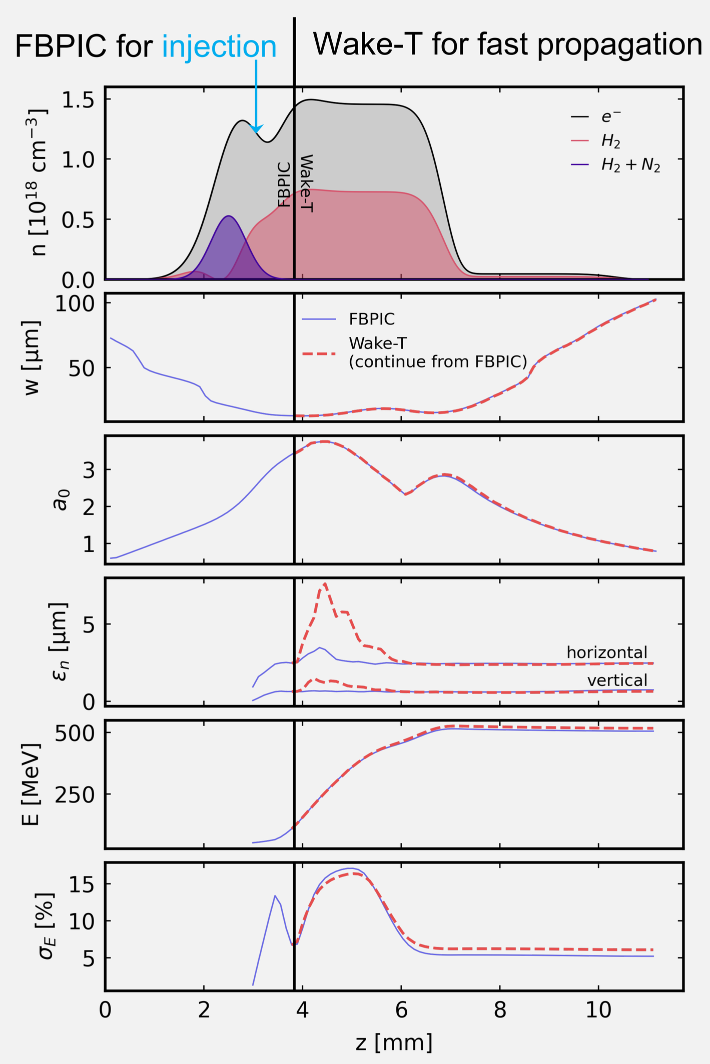
```
from lasy.profiles.longitudinal import LongitudinalProfileFromData
from lasy.profiles.transverse import TransverseProfileFromData
from lasy.profiles import CombinedLongitudinalTransverseProfile
from lasy.utils.phase_retrieval import gerchberg_saxton_algo
from lasy.laser import Laser

lo = (-75e-6, -75e-6, -50e-15) ; hi = (75e-6, 75e-6, 50e-15) ; npoints = (100, 100, 100)

longitudinal_profile = LongitudinalProfileFromData(exp_data1, -50e-15, 50e-15)
transverse_profile = TransverseProfileFromData(exp_data2, (-75e-6, -75e-6), (75e-6, 75e-6))
profile = CombinedLongitudinalTransverseProfile(wavelength, pol, energy, longitudinal_profile, transverse_profile)
laser = Laser("xyt", lo=lo, hi=hi, npoints=npoints, profile=profile)

# See LASY example for Gerchberg-Saxton algorithm

laser.propagate(-400e-6)
laser.write_to_file("reconstructed")
```

From simulation to simulation

LASY makes it easier to combine codes with different laser representations

- **FBPIC** [5]: electromagnetic PIC code capturing injection
  Laser pulse: self-consistent electric and magnetic fields
- **Wake-T** [6]: quasi-static code for fast & accurate simulations on a laptop
  Laser pulse: envelope of the vector potential

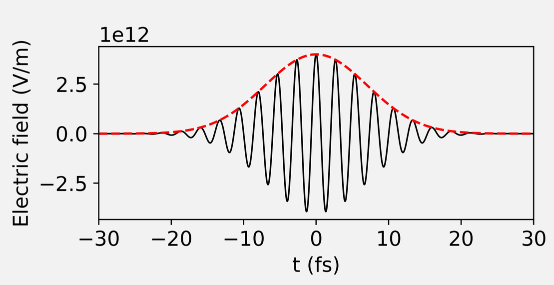





```
from lasy.profiles.from_openpmd_profile import FromOpenPMDProfile
from lasy.laser import Laser
from lasy.utils.laser_utils import field_to_vector_potential

lasy_profile = FromOpenPMDProfile(path, iteration, (1, 0), field, coord, prefix, theta)
laser = Laser("rt", (r_min, t_min), (r_max, t_max), (200,200), lasy_profile, n_azimuthal_modes=1)

a_env = field_to_vector_potential(laser.grid, laser.profile.omega0)
a_env = gaussian_filter(a_env, gaussian_filter_sigma)
```

The library

LASY is currently developed as a collaboration between DESY, BERKELEY LAB, loa, cea. More contributors are welcome!



Internally, LASY uses an envelope representation of the laser pulse.

class Profile
This class and its derived classes define the physical properties of the laser pulse
- Gaussian profile
- Profile from an openPMD file
- Combined transverse and longitudinal profiles (large varity of transverse profiles)

class Laser
The main LASY class, stores the laser pulse as a 2D cylindrical or 3D cartesian array for a given profile
- normalize pulse energy
- propagate in vacuum (powered by Axiprop [7])
- Write to file in the openPMD [8] standard

→ openPMD

Utils
A collection of functions to operate on laser pulses. Used internally, but designed to be easy to use externally
- Post-process/clean experimental data
- Decompose into Hermite-Gauss
- Gerchberg-Saxton algorithm
- Conversions between representations
- …

`pip install lasy`

https://github.com/LASY-org/lasy
https://lasydoc.readthedocs.io
https://www.openpmd.org
https://github.com/hightower8083/axiprop

Conclusion

- Using realistic laser profiles is critical to reproduce experimental results.
- LASY simplifies manipulations of laser pulses.
- Experiment-to-simulation and simulation-to-simulation workflows were demonstrated.

References

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Acknowledgements

We gratefully acknowledge the Gauss Centre for Supercomputing e.V. (www.gauss-centre.eu) for funding this project by providing computing time through the John von Neumann Institute for Computing (NIC) on the GCS Supercomputer JUWELS at Jülich Supercomputing Centre (JSC). This research was supported in part through the Maxwell computational resources operated at Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany. We acknowledge the Funding by the Helmholtz Matter and Technologies Accelerator Research and Development Program. This work was supported by the Director, Office of Science, Office of High Energy Physics, of the U.S. Department of Energy, under Contract No. DE-AC02-05CH11231.

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Poster 381 at EAAC 2023, Isola d'Elba, Italy