Multi-Objective Optimization With ACE3P and Impact

David Bizzozero[1], Ji Qiang[1],
Lixin Ge[2], Zenghai Li[2],
Cho-Kuen Ng[2], and Liling Xiao[2]

[1]: Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720
[2]: SLAC National Accelerator Laboratory, 2575 Sand Hill Rd., Menlo Park, CA 94025

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Overview of Accelerator Optimization

Accelerator layout and design optimization

→ important for building future machines

Current methodology:

1. Optimize each physical component separately
2. Optimize lattice design with fixed geometry components

Issues:

- Separate codes for each component and lattice
- Final design not globally optimized (e.g. beam dynamics simulations cannot change cavity shape)

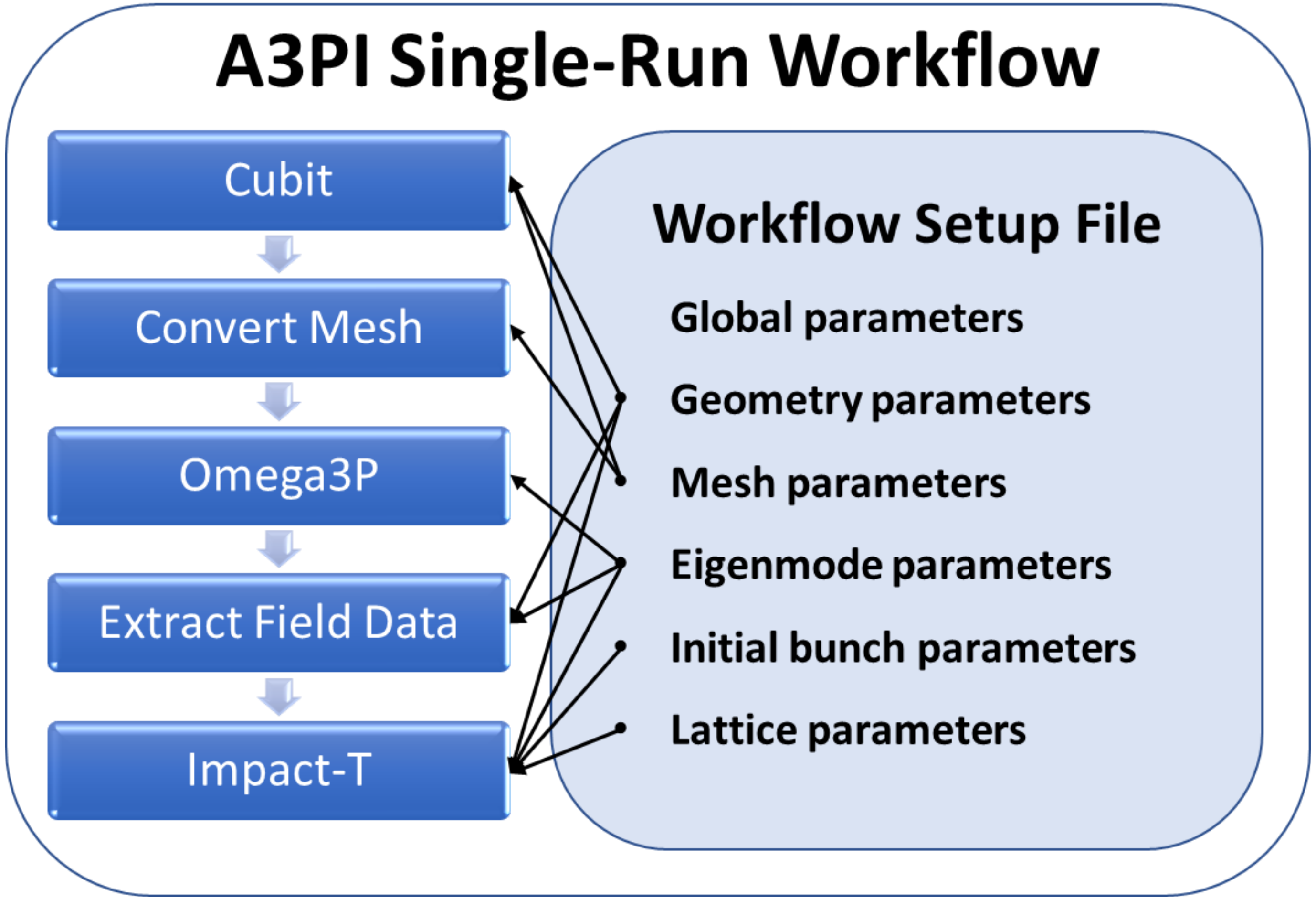
New approach:

- Workflow management system to integrate codes
  → global multi-objective optimization

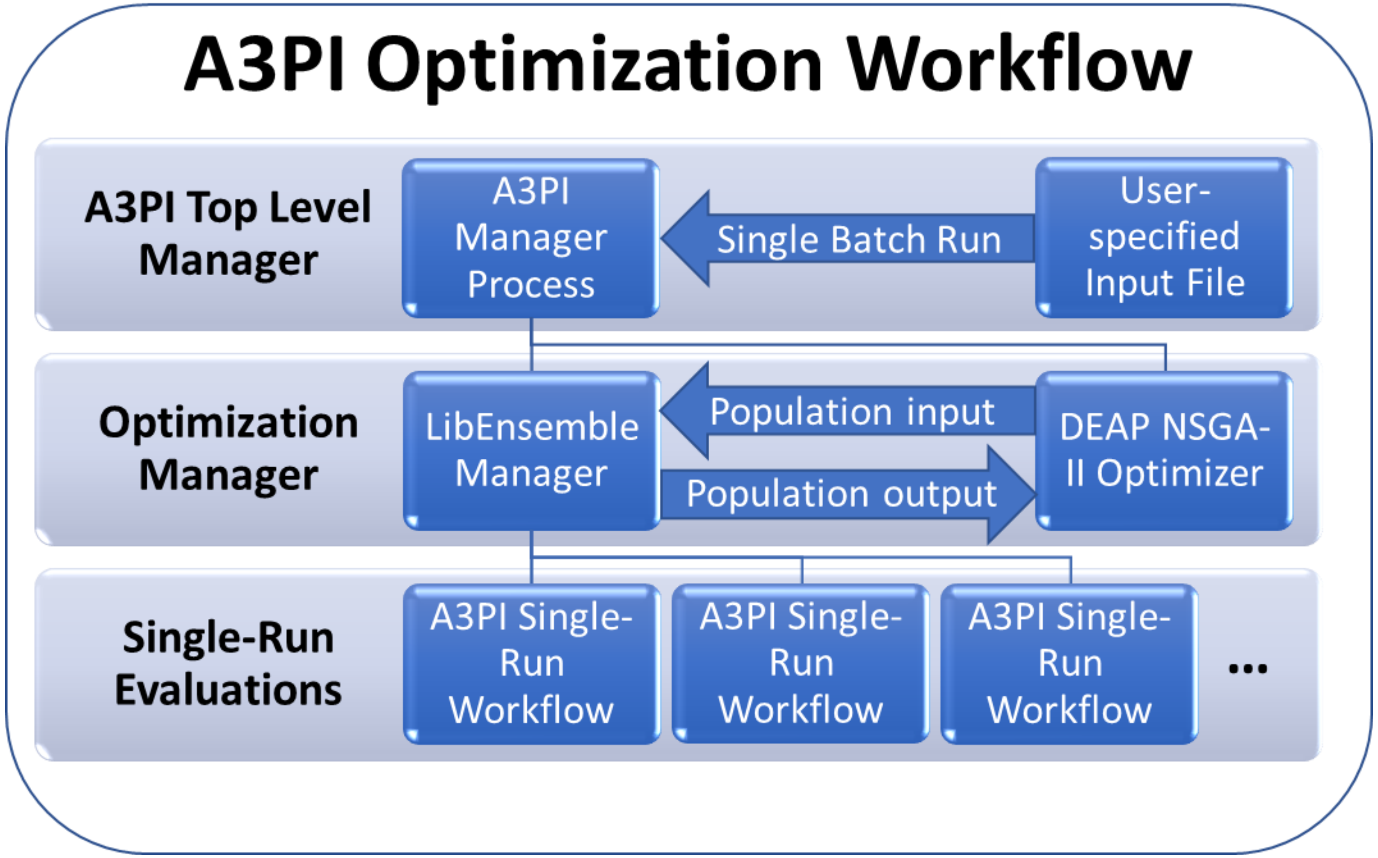
Introducing A3PI (ACE3P with IMPACT)

A3PI Workflow Layout:

- Python-based workflow
- One input file contains all parameters for all codes
- HPC tasks run sequentially within workflow
- Parameter values updated for new evaluations
- Encapsulate workflow as “black-box” function
- Modular code design



Using A3PI for Multi-Objective Optimization on HPCs



A3PI Optimization Hierarchy:

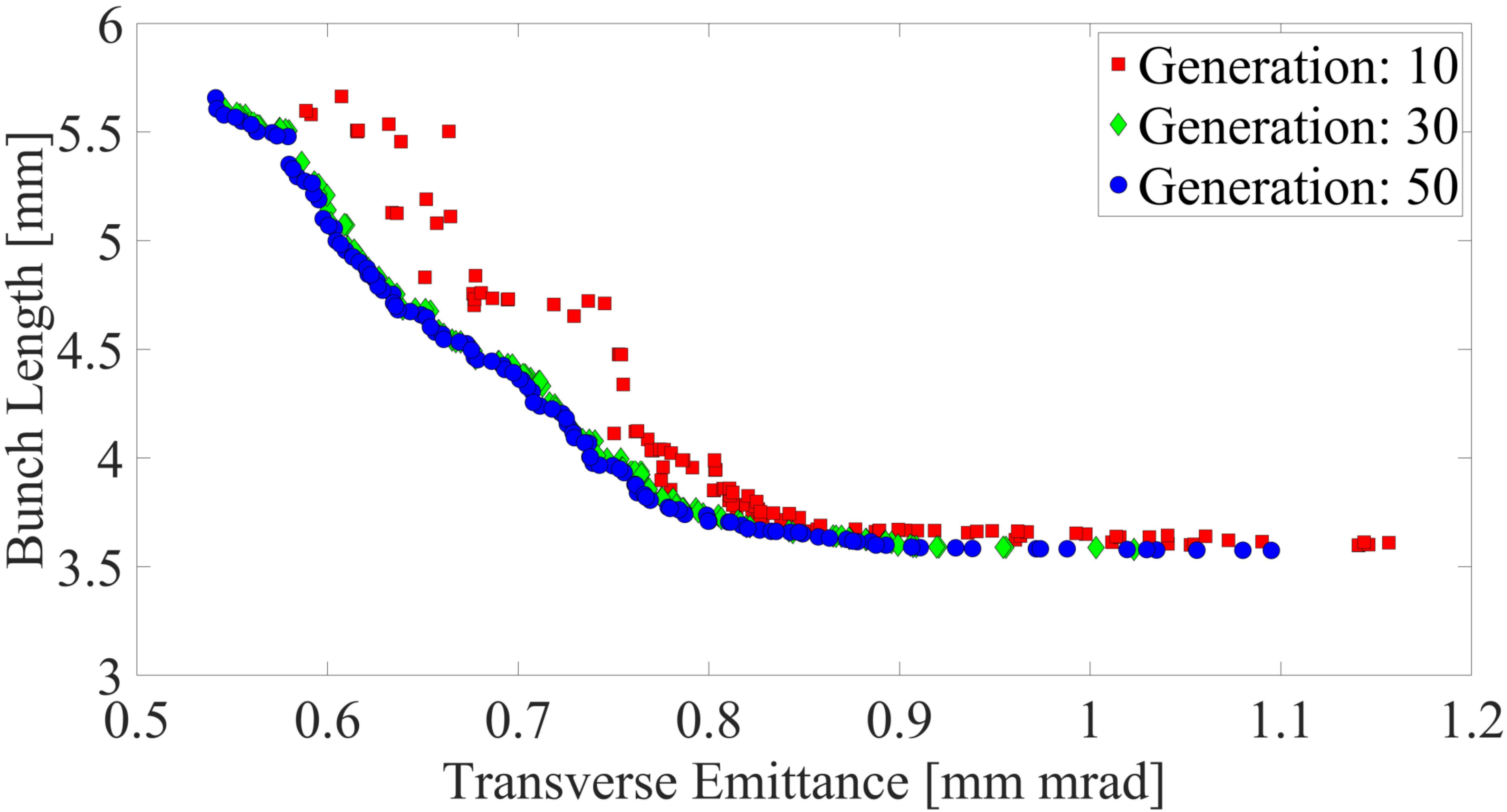
- Single-run workflows as "black-box" functions
- Differential evolution algorithms (NSGA-II) from DEAP library
- Multi-node multi-worker HPC job control with libEnsemble
- All settings/options in 1 file (submit as 1 job to HPC)

Injector Optimization Example

Accelerator injector with movable cathode (test model):

- Photocathode, solenoid, four 9-cell boosting cavities
- Input (9D parameter space):
  - Cathode stalk position d_{cathode} and driving phase θ_{cathode}
  - Laser spot size $\sigma_{x,y}$ and pulse length σ_z
  - Focusing solenoid strength B_{sol}
  - Boosting cavity phases $\theta_1, \theta_2, \theta_3, \theta_4$
- Output to minimize (2 objectives):
  - Final transverse RMS emittance $\epsilon_{\perp}$
  - Final bunch length σ_{bunch}
- Other parameters fixed (e.g. bunch charge, mode freq.)
- Optimization via NSGA-II with population 128 for 50 gen.
- Used 128 KNL nodes on Cori@NERSC for 1 hour*

A3PI Optimization Test



A3PI Additional Tools

A3PI Visualization Tools in MATLAB:

- **Mesh** plotting (acdtool NetCDF mesh)
- **Field** plotting (Omega3P field mode)
- **Particle** plotting (Impact-T particles)
- **Optimization** plotting (libEnsemble history array)

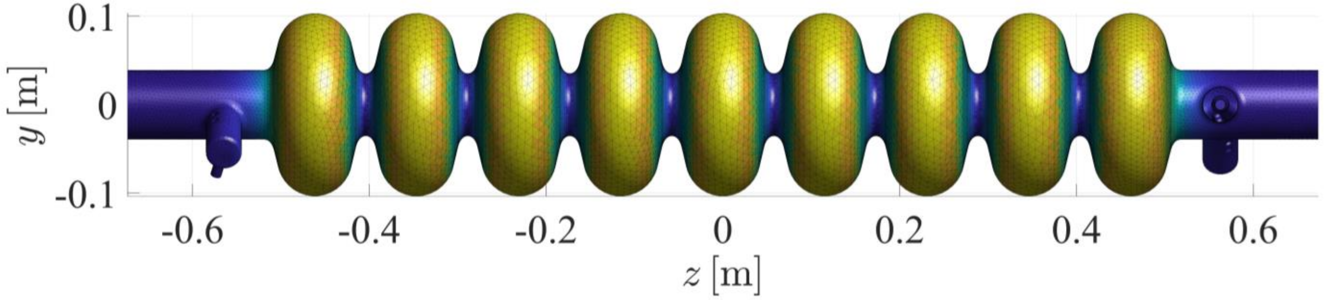
Customizable scripts with options:

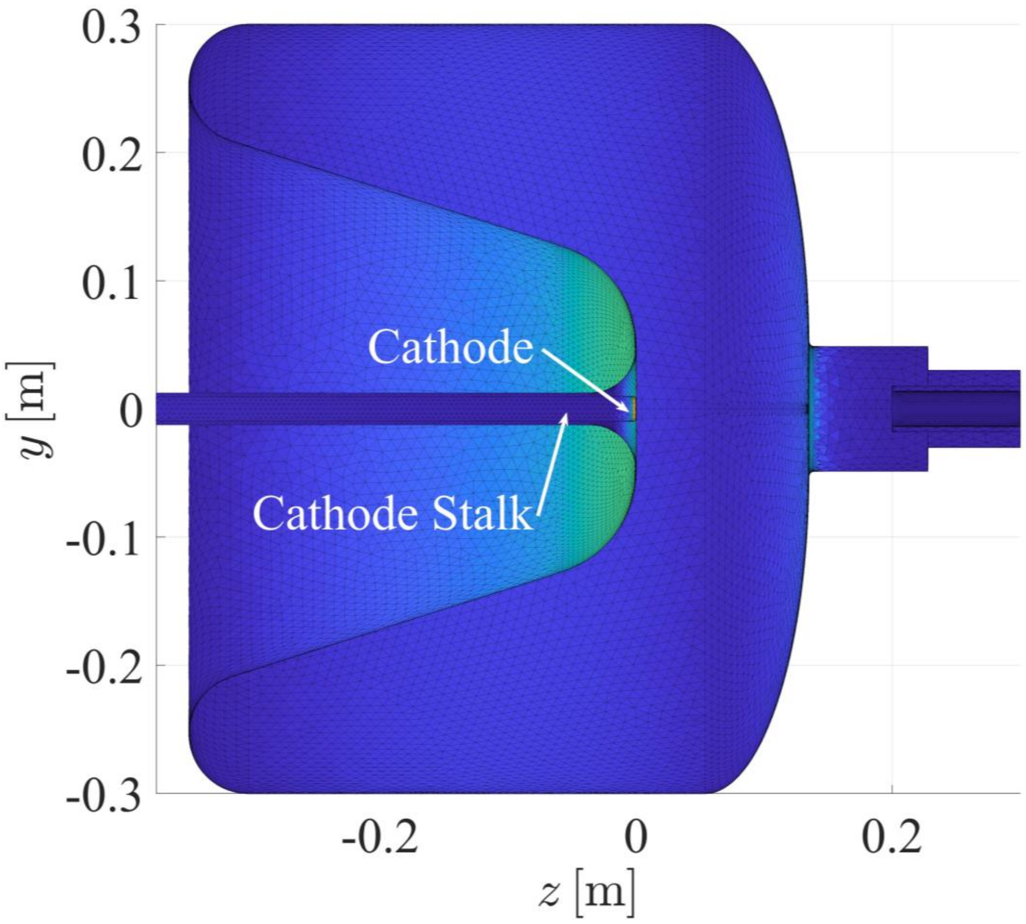
- **Interactive** mode – to explore data
  - Full 3D visualization for meshes, fields, and particles
  - Sliders to select population generation or time-slice
- **Animation** mode – to export videos
  - Video options such as background lighting

A3PI Mesh and Field Plotting Demo

Customizable options:

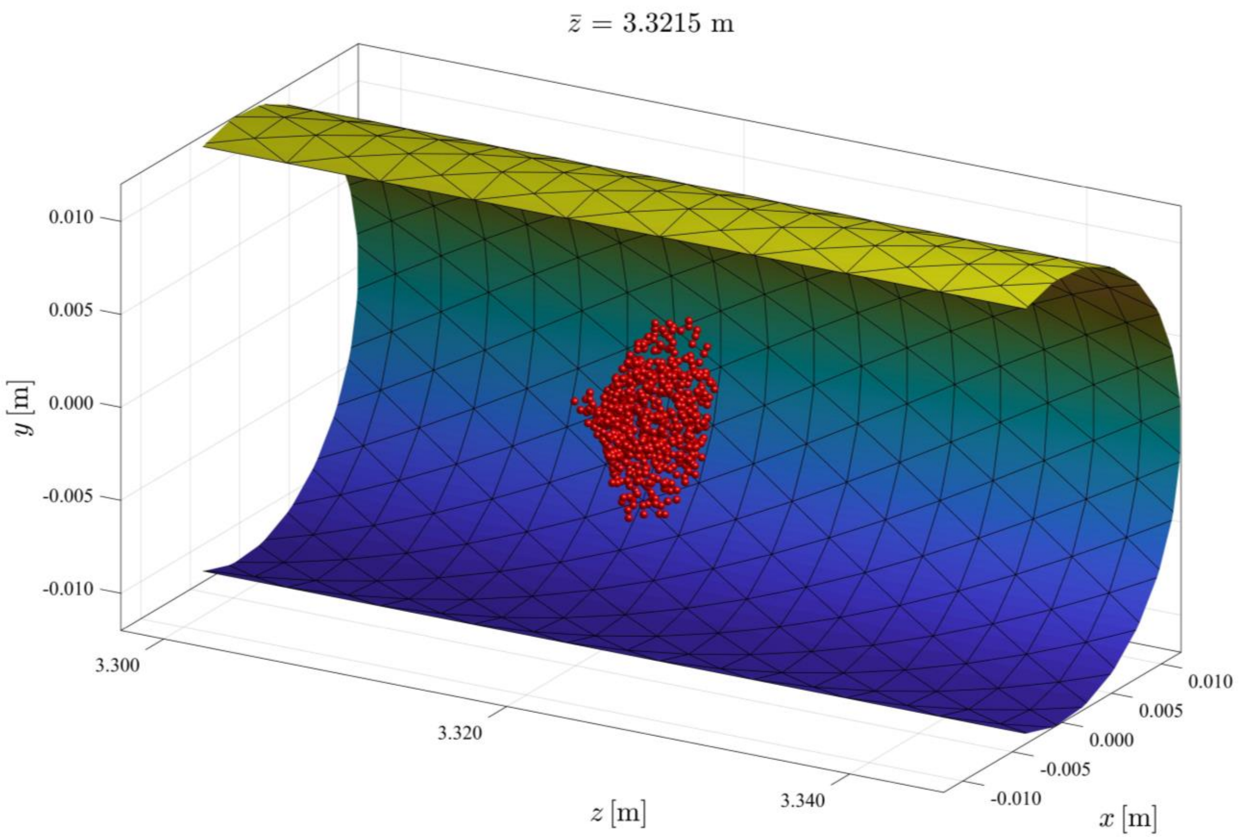
- Full 3D camera controls
- Mesh color/visibility
- Lighting and field color options
- Overlay Omega3P modal fields



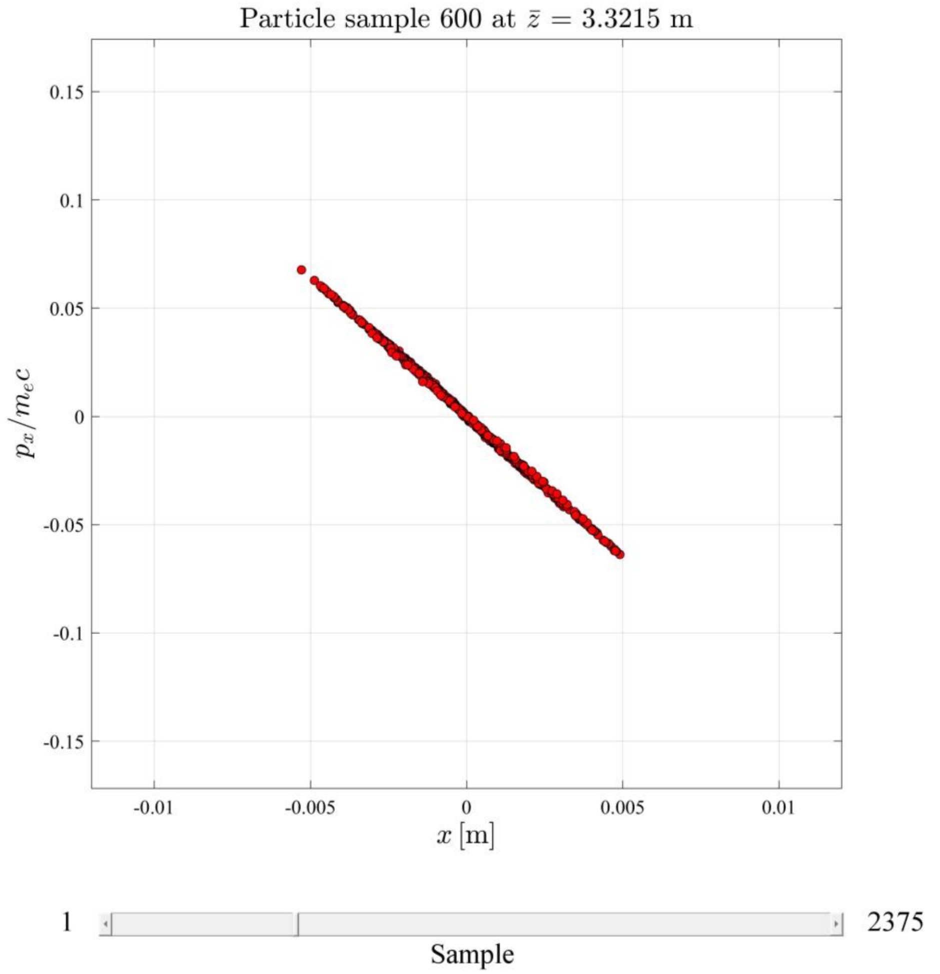


A3PI Particle Plotting Demo

Particle position animation frames



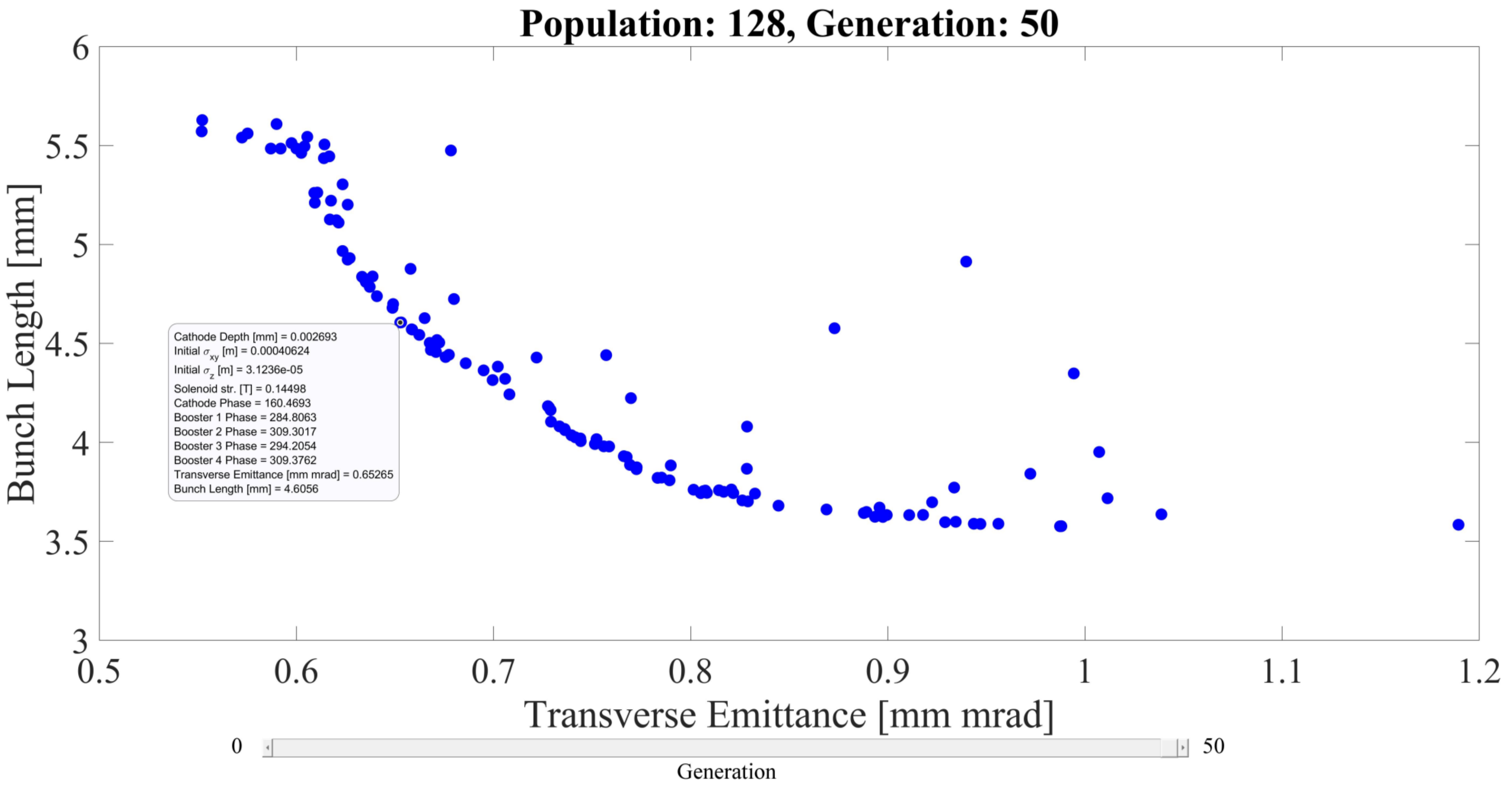
Particle phase space plots



A3PI Population History Demo

Interactive population browser by generation

Custom data tooltip displays input/output values



Summary

Developed A3PI (ACE3P with Impact)

- Written in Python with some MATLAB utilities
- Interfaces codes (e.g. Cubit, Omega3P, Impact-T)
- Manages all aspects of workflow with 1 main input file
- Includes useful data visualization options
- Optimizes multi-objective problems with DEAP
- Runs on HPC systems with libEnsemble

Future Work:

- Perform optimization with realistic injector model
- Add functionality with more codes
- Test compatibility with more HPC systems

Acknowledgements and References

This work is supported by the US Department of Energy under contracts DE-AC02-05-CH11231 and DE-AC02-76-SF00515.

LibEnsemble was developed at Argonne National Laboratory and is available at: https://libensemble.readthedocs.io/

DEAP was developed at the Computer Vision and Systems Laboratory at Université Laval, in Quebec city, Canada and is available at: https://deap.readthedocs.io/

ACE3P was developed at SLAC National Accelerator Laboratory and more information is available at: https://portal.slac.stanford.edu/sites/ard_public/acd/Pages/acmod.aspx and https://confluence.slac.stanford.edu/display/AdvComp

Cubit™ was developed at Sandia National Laboratories and is available at: https://cubit.sandia.gov/

Impact-T was developed by Ji Qiang at Lawrence Berkeley National Laboratory and is available at: https://amac.lbl.gov/~jiqiang/IMPACT-T/index.html

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