

JSPEC : A PROGRAM FOR IBS AND ELECTRON COOLING SIMULATION

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Abstract

JSPEC (JLab Simulation Package on Electron Cooling) is an open-source C++ program developed at Jefferson Lab to simulate the evolution of the ion beam under the intrabeam scattering effect and/or the electron cooling effect. JSPEC includes various models of the ion beam, the electron beam, and the friction force, aiming to reflect the latest advances in the field and to provide a useful tool to the community. JSPEC has been benchmarked against other cooling simulation codes and experimental data. A Python wrapper for Python 3.x environment has also been developed, which allows users to run JSPEC simulations in a Python environment and makes it possible for JSPEC to collaborate with other accelerator and beam modeling programs, as well as plentiful Python tools in data visualization, optimization, machine learning, etc. A Fortran interface is being developed, aiming at seamless call of JSPEC functions in Fortran.

Introduction

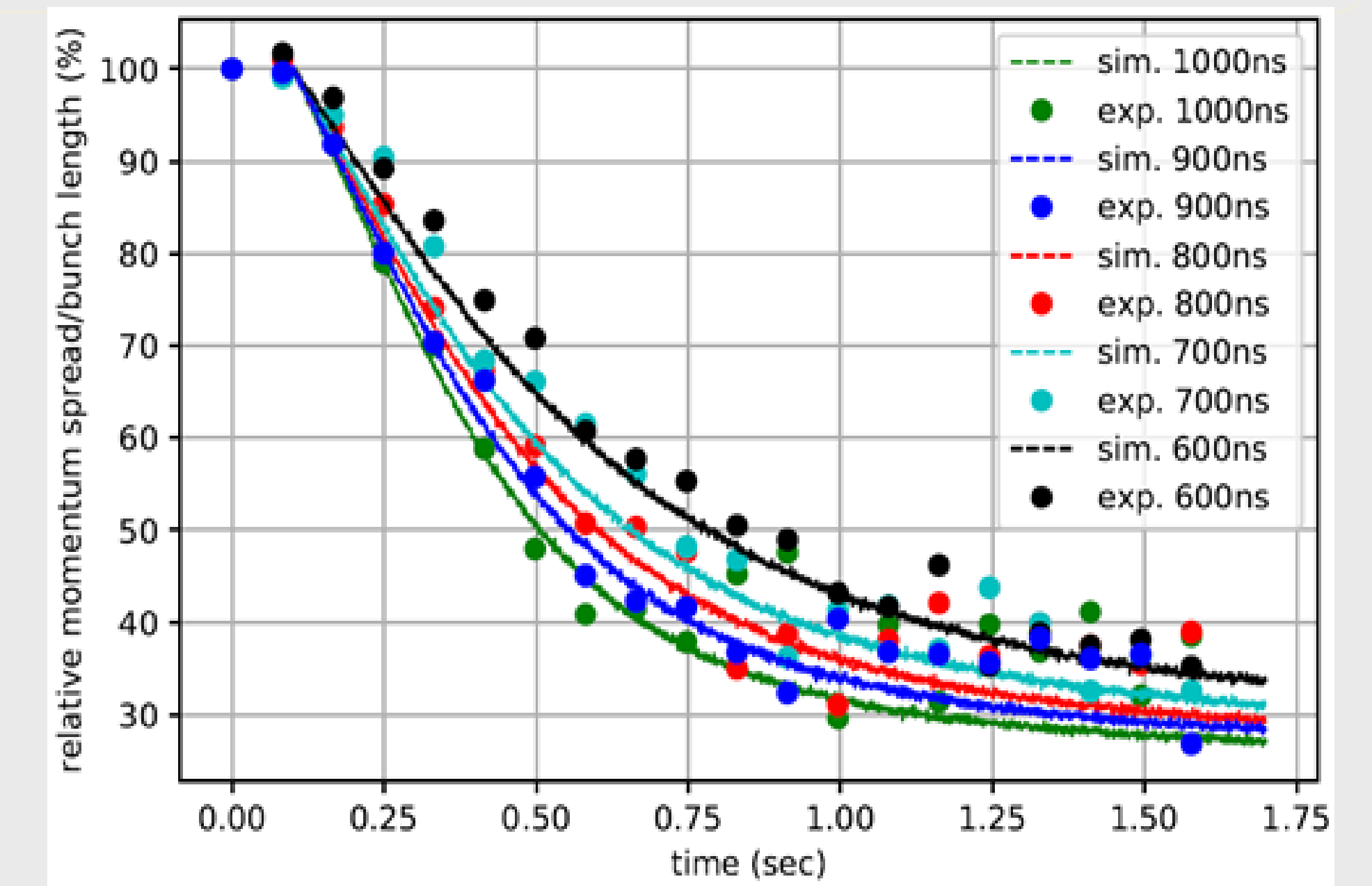
Jlab Simulation Package for Electron Cooling (JSPEC)

- Efficient C++ code for intrabeam scattering (IBS) effect and electron cooling simulation.
- Ion beam model: coasting or bunched
- Electron beam model: DC or bunched with various shapes, e.g. Gaussian, beer can, hollow beam, etc. User-defined arbitrary shape is also supported.
- Various formulas for friction force calculation in magnetized cooling or non-magnetized cooling.
- Supports ion beam dispersion and electron beam dispersion.
- Source code and documents available at *github*: <https://github.com/zhanghe9704/electroncooling>
- Support parallel computation in shared-memory structure with OPENMP
- pyJSPEC port most JSPEC functions to Python 3.x environment. <https://github.com/zhanghe9704/jspec2-python>
- A FORTRAN interface is under development.
- Under active maintenance and development.

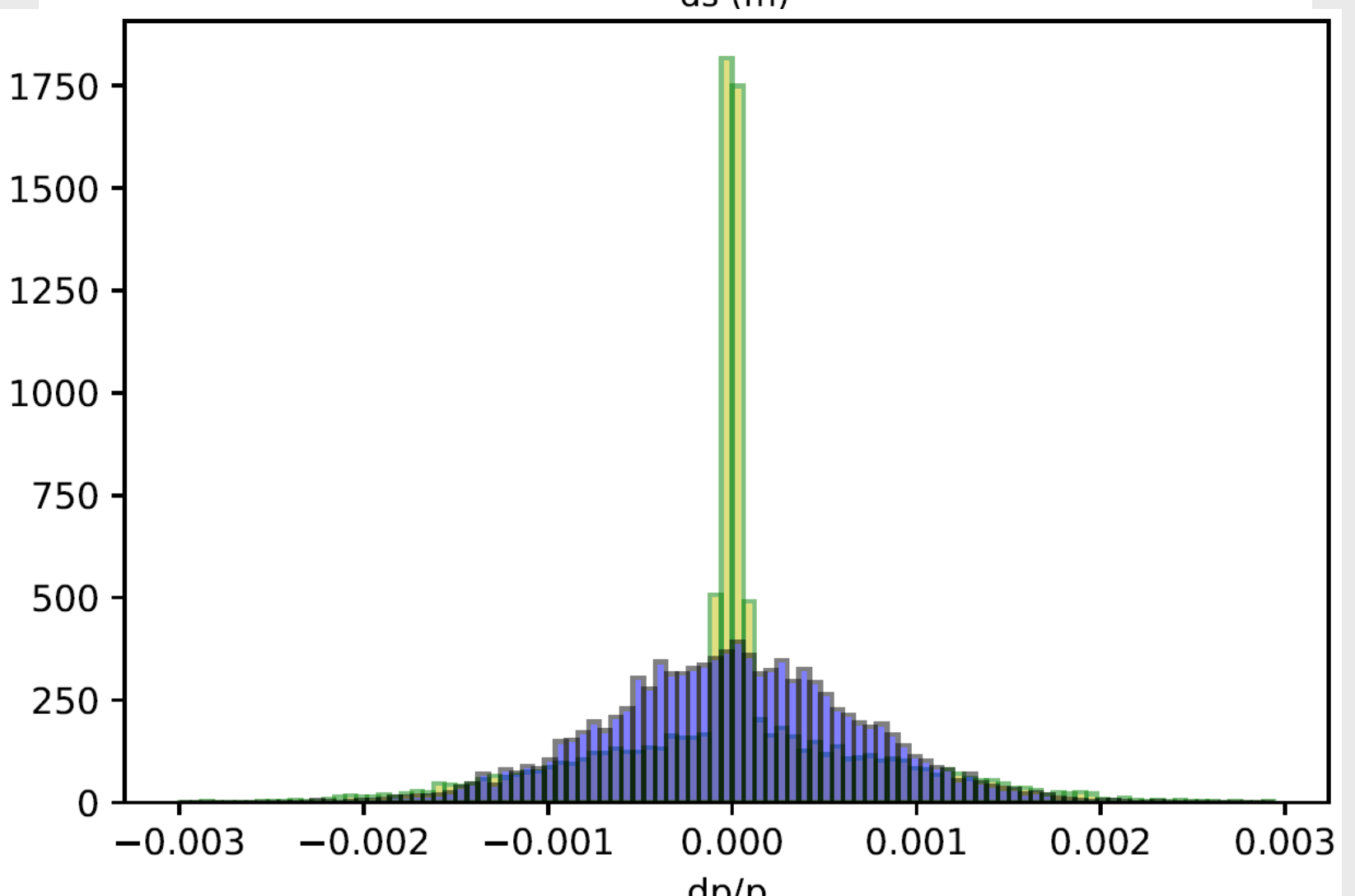
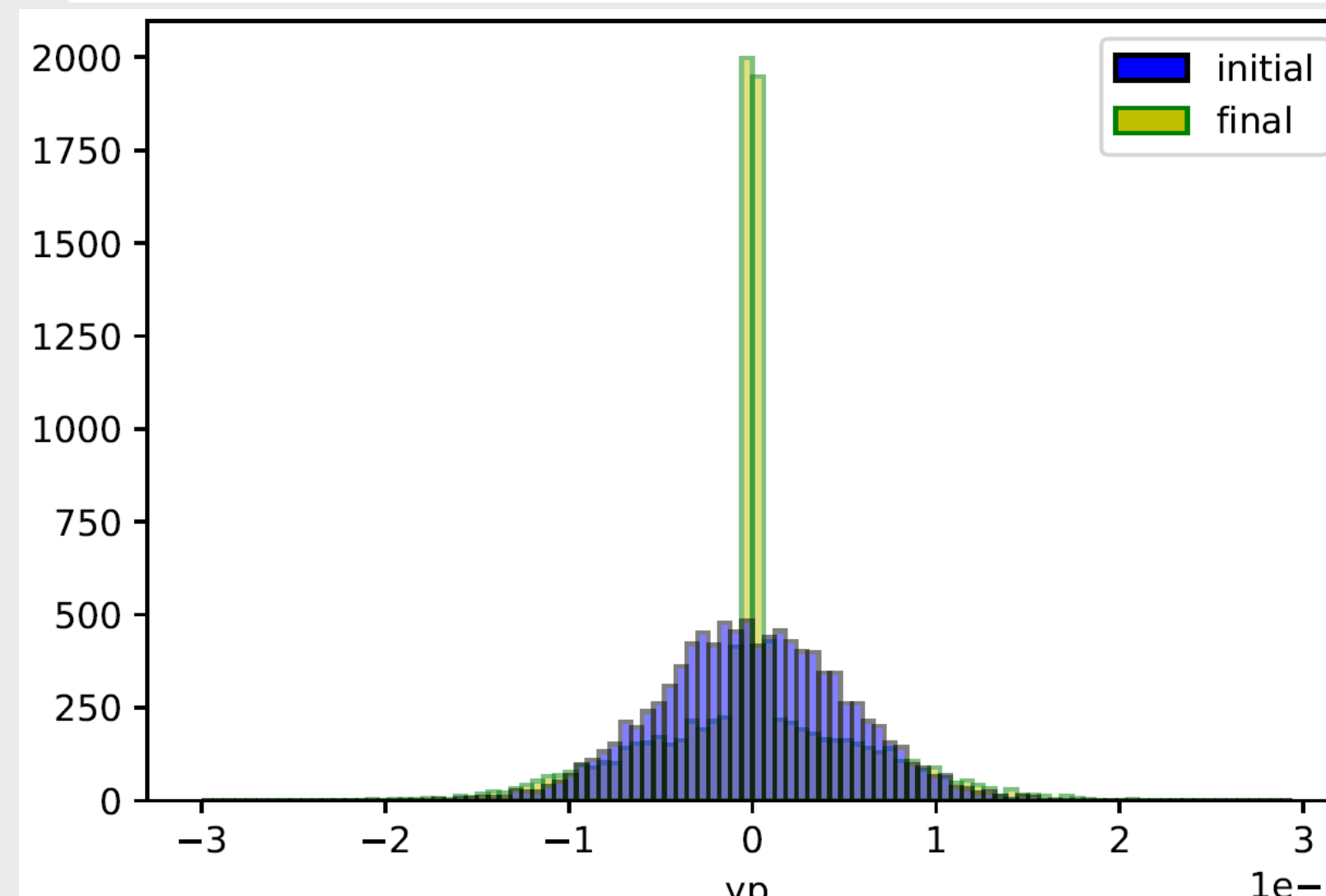
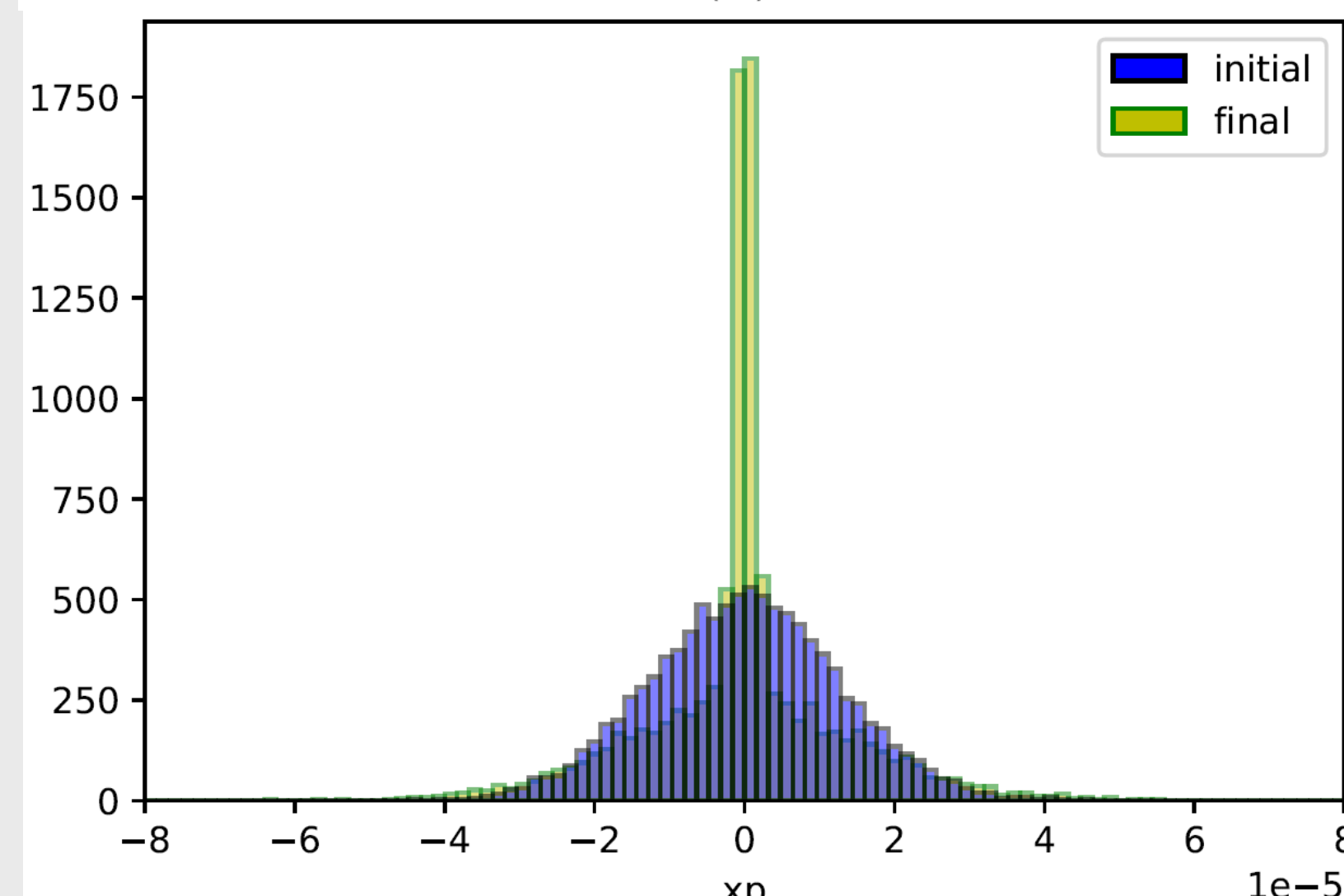
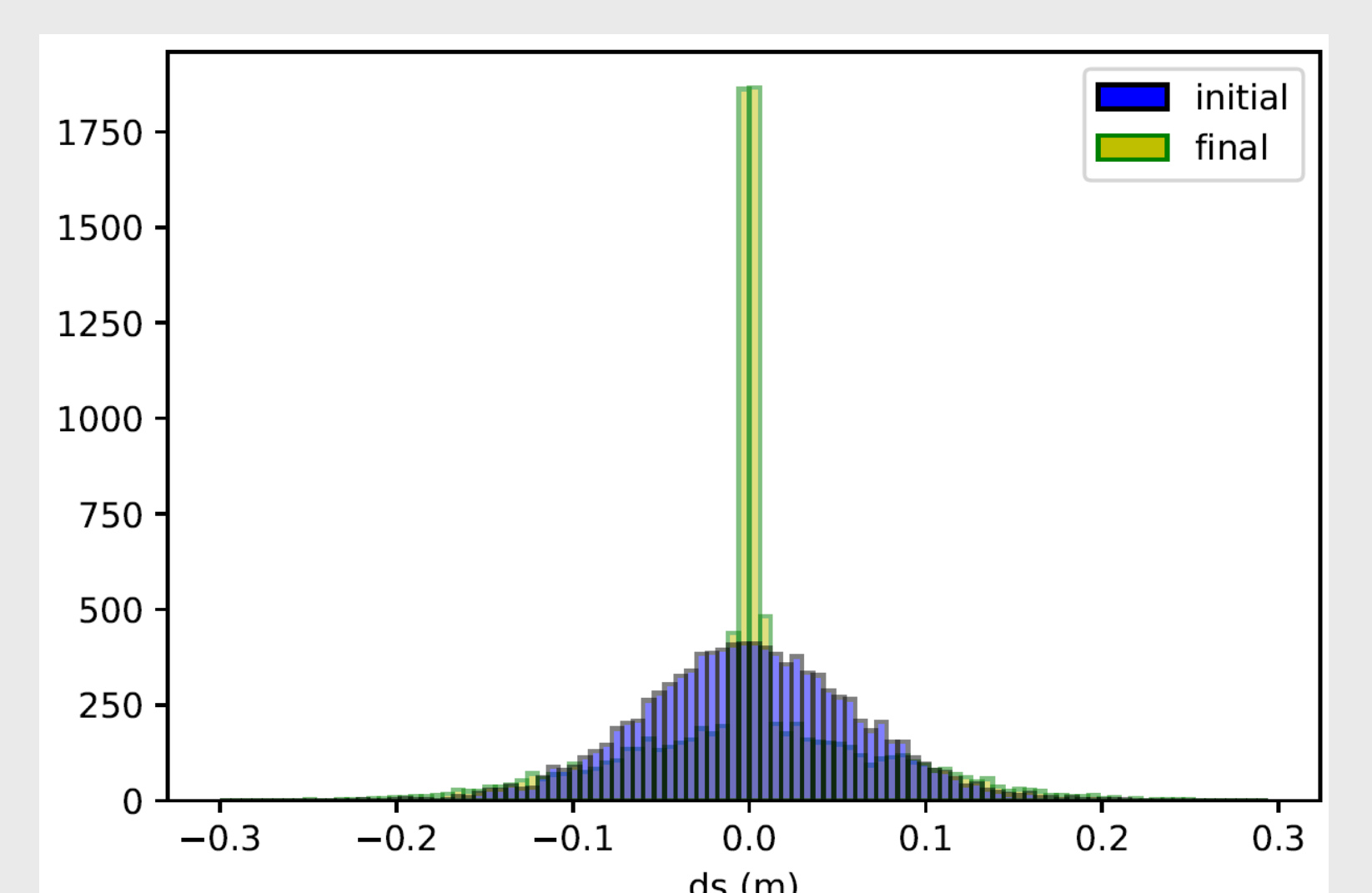
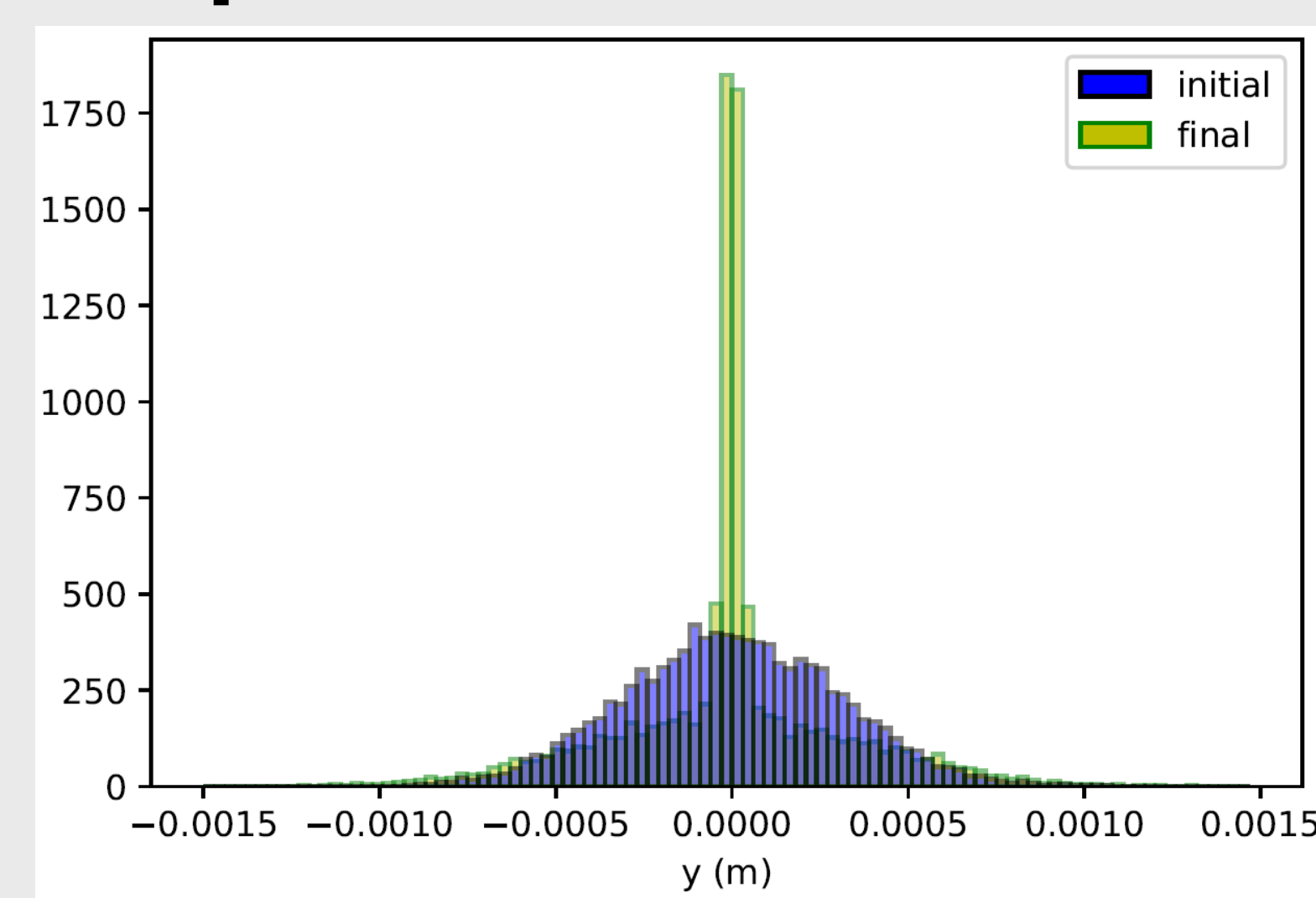
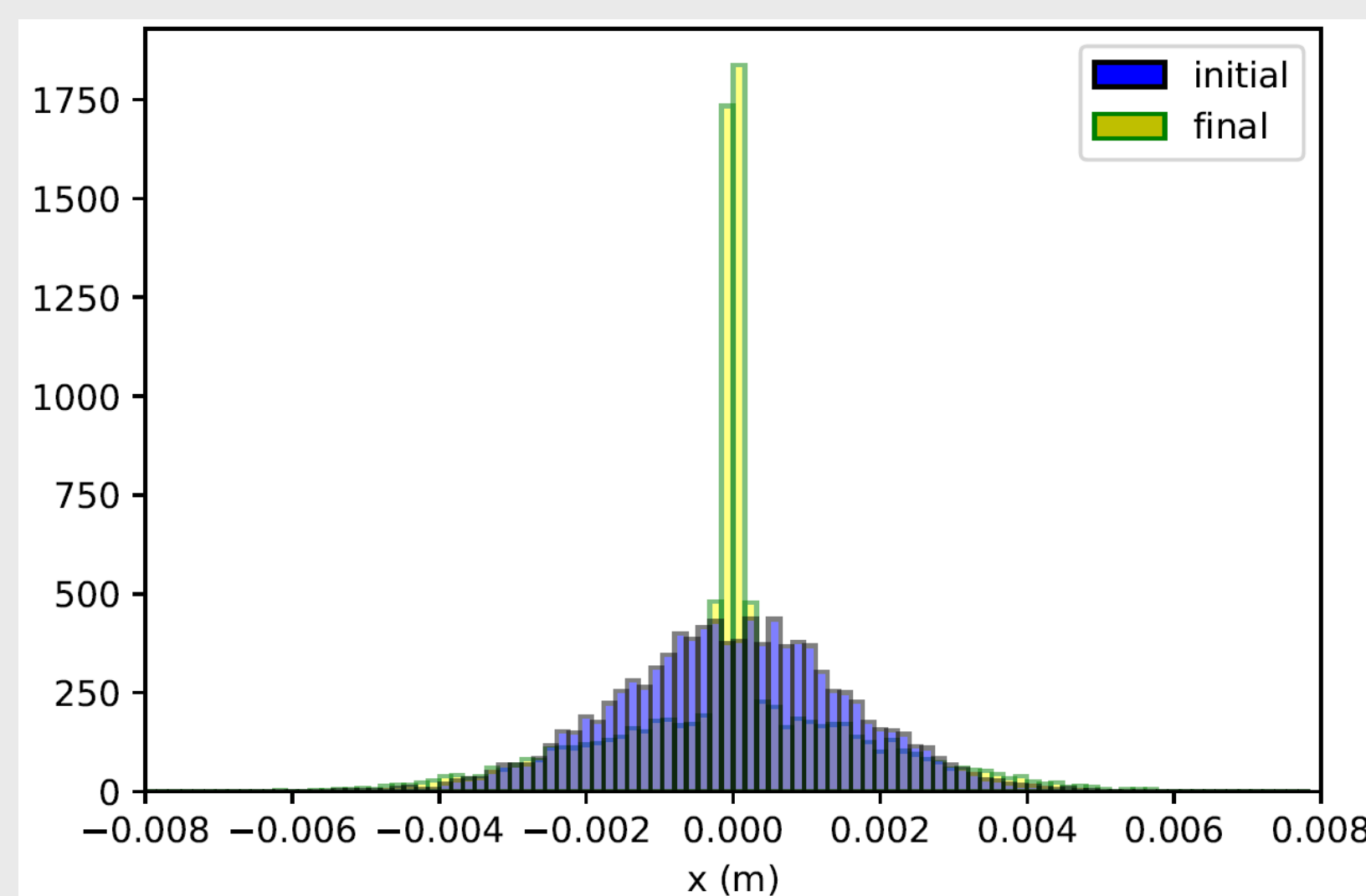
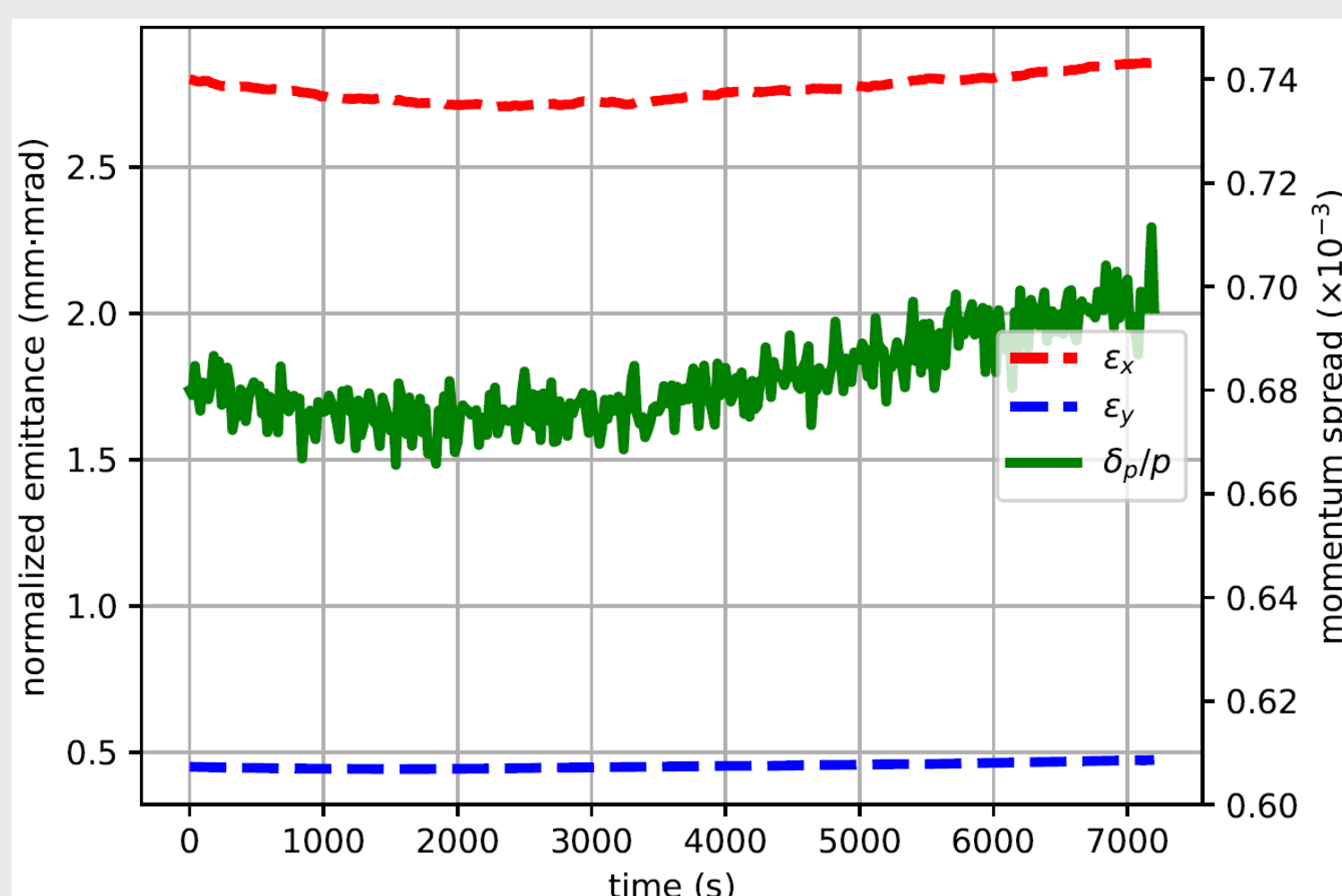
Benchmark with Experiments

Cooling of $^{86}\text{Kr}^{25+}$ beam (5 MeV/nucleon) using electron pulses with the length from 600 ns to 1000 ns in collaboration of Jefferson Lab (US) and Institute of Modern Physics (China) from 2016 to 2019.

Simulations and experiments agree well.



JSPEC Examples



Parameters in the above simulation come from Fanglei Lin's talk on Monday 2:30 PM: Perspective of a Dual Energy Storage Ring Cooler for Hadron Beam Cooling.

```
1 section_scratch
2   ion_mass = 938.2720882
3   ion_ke = 274061.728
4   ion_gamma = 1 + ion_ke/ion_mass
5
6 section_ion
7   charge_number = 1
8   mass = ion_mass
9   kinetic_energy = ion_ke
10  norm_emit_x = 2.8e-06
11  norm_emit_y = 4.5e-07
12  momentum_spread = 0.00068
13  particle_number = 6.9e10
14  rms_bunch_length = 0.06
15
16 section_ring
17  lattice = ring-lattice.txt
18
19 section_ibs
20  model = bm
21  log_c = 20.0
22  coupling = 0.2
23
24 section_cooler
25  length = 120
26  section_number = 1
27  magnetic_field = 4
28  bet_x = 60
29  bet_y = 60
30  disp_x = 2.0
31
32 section_e_beam
33  gamma = ion_gamma
34  tmp_tr = 4665.2223
35  tmp_l = 0.2798
36  shape = bunched_gaussian
37  sigma_x = 0.00074
38  sigma_y = 0.00016
39  sigma_z = 0.025
40  e_number = 4.14e11
41
42 section_ecool
43  sample_number = 10000.0
44  force_formula = PARKHOMCHUK
45
46 section_run
47  create_ion_beam
48  create_ring
49  create_e_beam
50  create_cooler
51  set_n_thread 4
52  calculate_ibs
53  calculate_ecool
54  total_expansion_rate
55
56 section_simulation
57  ibs = on
58  e_cool = on
59  time = 7200.0
60  step_number = 3600
61  model = particle
62
63 section_run
64  run_simulation
```

JSPEC

```
1 import jspec
2
3 #define variables
4 ...
5
6 #create the ion beam
7 p_beam = jspec.Beam(n_charge, n_mass, ke, ex, ey, dp, ds, np)
8
9 #create the ring
10 lat = jspec.Lattice("test.tfs")
11 ring = jspec.Ring(lat, p_beam)
12
13 #create the cooler
14 cooler = jspec.Cooler(length, section_number, magnetic_field,
15                       twiss_beta, twiss_beta, dx, dy)
16
17 #create electron bunch
18 e_beam = jspec.GaussianBunch(ne, sigma_x, sigma_y, sigma_z)
19 e_beam.set_gamma(gamma)
20 e_beam.set_tpr(t_tr, t_l)
21
22 #calculate electron cooling rate
23 force_solver = jspec.ForcePark() #Parkhomchuk formula
24 n_sample = 40000
25 ecool_solver = jspec.ECool()
26 rate = ecool_solver.rate(force_solver, p_beam, n_sample, cooler, e_beam, ring)
27
28 #calculate IBS rate
29 log_c = 20.2
30 ibs_solver = jspec.IBSolver_BM(log_c)
31 rate = ibs_solver.rate(lat, p_beam)
32
33 #create ion samples
34 p_samples = jspec.Ions_MonteCarlo(n_sample)
35 p_samples.set_twiss(cooler)
36 p_samples.create_samples(p_beam)
37
38 #run simulation
39 simulator = jspec.ParticleModel(time, n_step)
40 simulator.set_ibs(True)
41 simulator.set_ecool(True)
42 simulator.run(p_beam, p_samples, cooler, e_beam, ring, ibs_solver,
43             ecool_solver, force_solver)
```

Python

```
1 program main
2   use jspec
3   use iso_c_binding
4   implicit none
5
6   type(Beam) :: my_beam
7   type(Lattice) :: my_lattice
8   type(Ring) :: my_ring
9   type(Cooler) :: my_cooler
10  type(FrictionForceSolver) :: my_force_solver
11  type(EBeam) :: my_ebeam
12  type(ECoolRate) :: rate_ec
13
14  ! Define variables
15  integer(c_int) :: charge = 1
16  real(c_double) :: mass = 938.272
17  ...
18  ! Create ion beam
19  my_beam = create_beam(charge, mass, ke, ex, ey, dp, ds, np)
20
21  ! Create the lattice from some file
22  my_lattice = create_lattice("lattice.txt")
23
24  ! Create a ring
25  my_ring = create_ring(my_lattice, my_beam)
26
27  ! Create a cooler
28  my_cooler = create_cooler(length, n_section, mag_field, &
29                          twiss_beta, twiss_beta)
30
31  ! Create friction force solver
32  my_force_solver = create_force_solver(PARKHOMCHUK)
33
34  ! Create electron beam with Gaussian distribution
35  my_ebeam = create_gaussian_bunch(ne, sigma_x, sigma_y, ds)
36  call ebeam_set_gamma(my_ebeam, gamma)
37  call ebeam_set_temperature(my_ebeam, tmp_tr, tmp_l)
38
39  ! Calculate cooling rate
40  rate_ec = create_ecool_rate_calculator()
41  call ecool_rate(rate_ec, my_force_solver, my_beam, n_sample, &
42                my_cooler, my_ebeam, my_ring, rx, ry, rs)
43end program main
```

Fortran