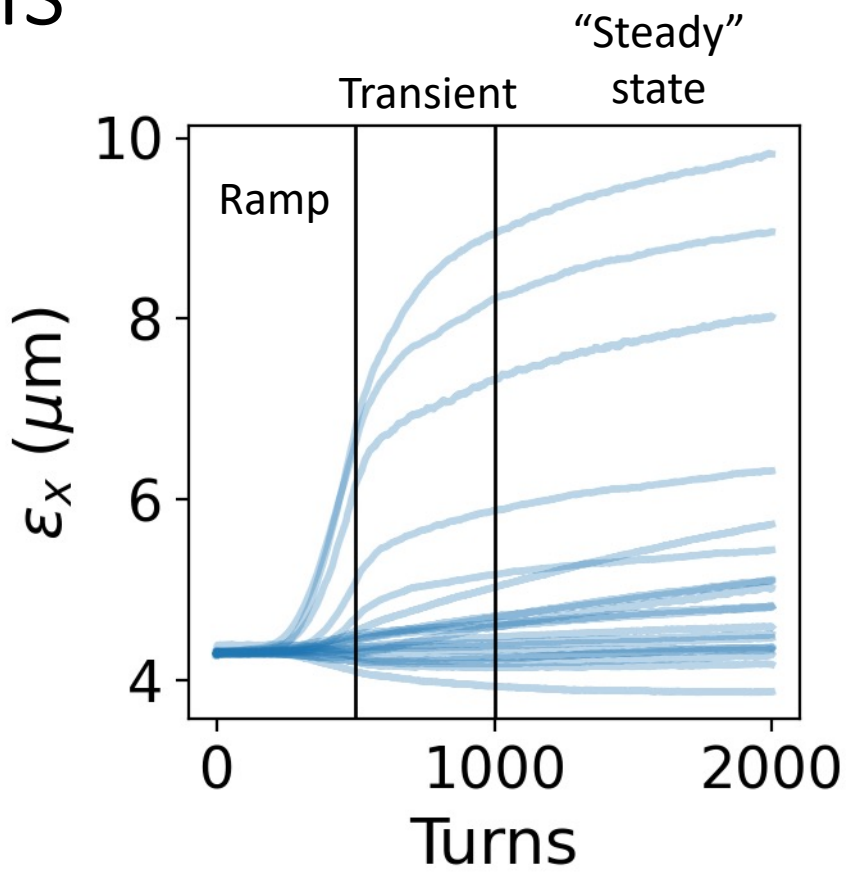
Simulations of proton injection into IOTA with space-charge

Usual space-charge simulations

We try to match the initial beam distribution to the optics of the ring and let the beam evolve from this matched state. Two methods:

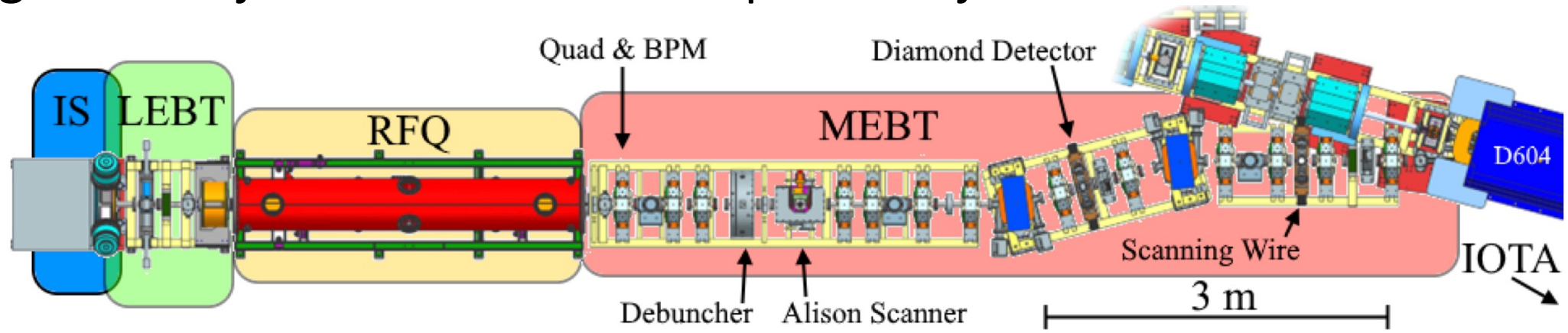
1. Match initial distribution to bare lattice perturbed with linear space-charge. Used in MAD-X space-charge simulations.
2. Match initial distribution to bare lattice and then steadily increase charge on each turn, keeping the number of macro-particles constant. – Typically used in PIC simulations.



Reality

Single shot injection from the IOTA proton injector.

20 mA,
350 us



Bunch length: 0.3 ns -> 6.6 mm

Max Intensity (4 mA from IS): 8.74 x 10^{12}

-> 760 mA of stored current in IOTA

What happens when we inject this into IOTA?

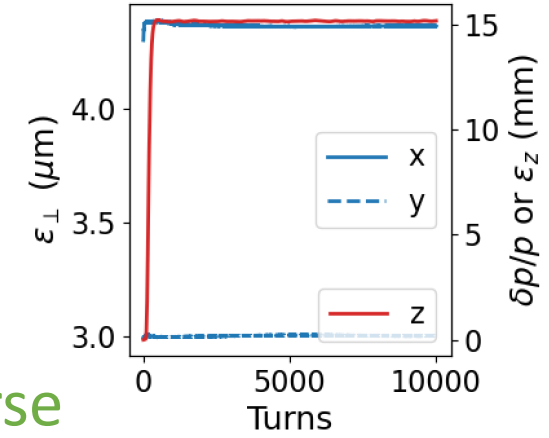
Table 1: Beam parameters for injection into IOTA.

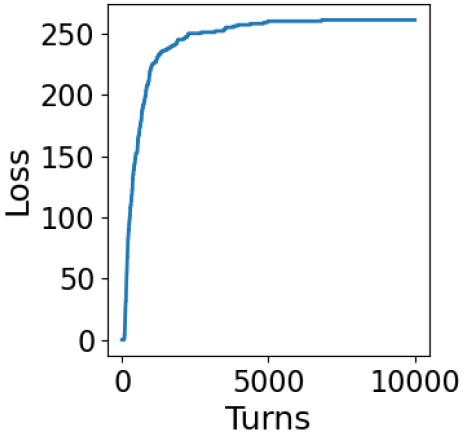
Parameter	Nominal	Range	Unit
Kinetic energy (K_p)	2.5	$2.4 - 2.6$	MeV
Emittances (ϵ_x, ϵ_y)	4.3, 3	$3.0 - 5.0$	μm
Momentum spread ($\sigma_{\delta,\mathrm{inj}}$)	1×10^{-3}	$1 - 2 \times 10^{-3}$	
Bunch Length ($\sigma_{z,\mathrm{inj}}$)	6.6		mm
Protons per pulse (N)	—	$\leq 8.74 \times 10^{12}$	

No space-charge

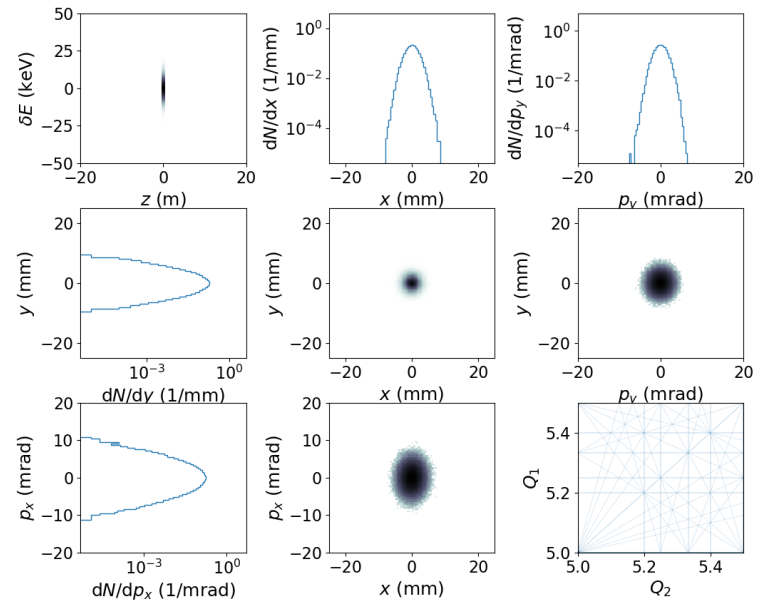
Using the 1IO lattice for the DN magnet.

Beam de-bunches in ~ 1000 turns. Transverse phase space remains untouched.

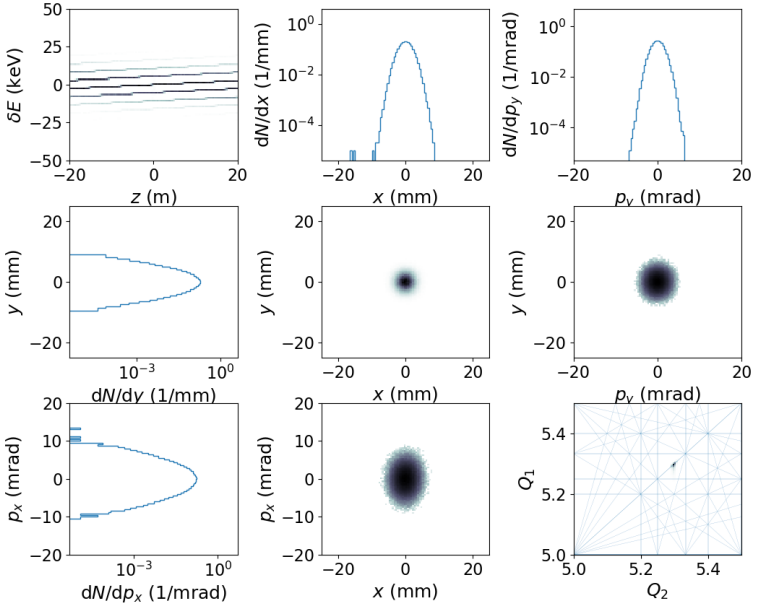




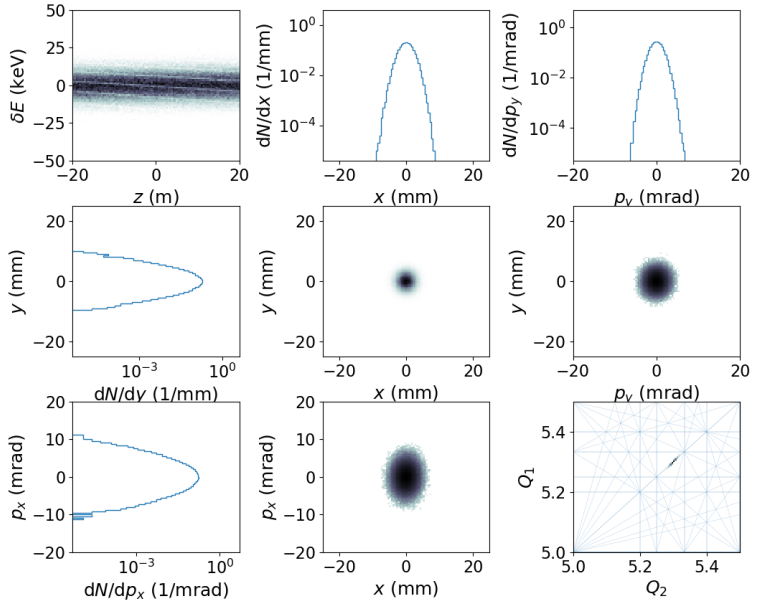
t = 0



t = 1000

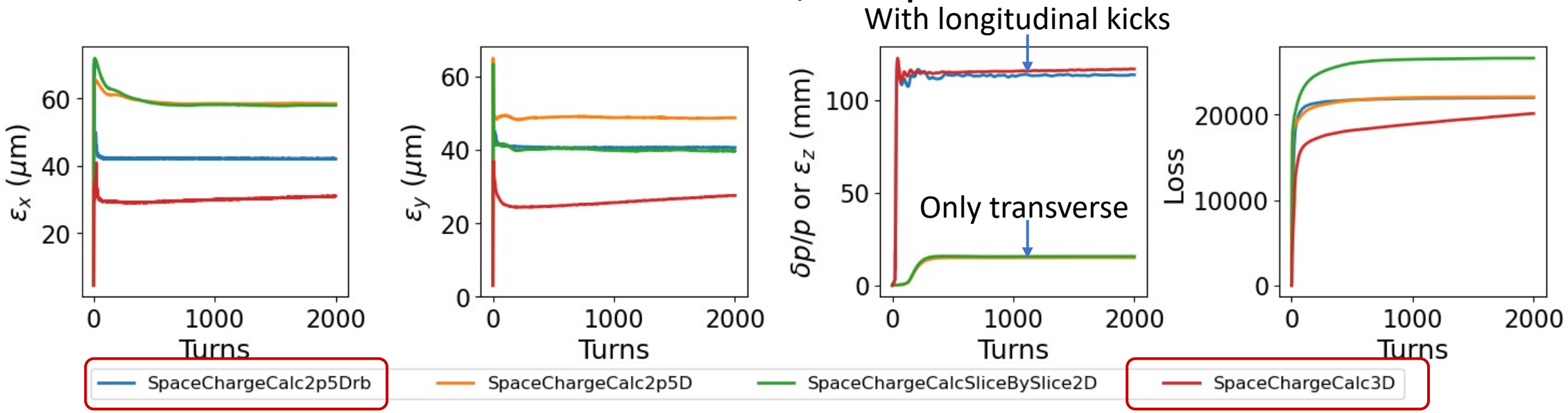


t = 10000



Simulations with space-charge in PyORBIT – different models

Ran simulations with an intensity corresponding to a stored current of 1.27 mA in IOTA. SC Grid: 64x64x64, 10^5 particles.

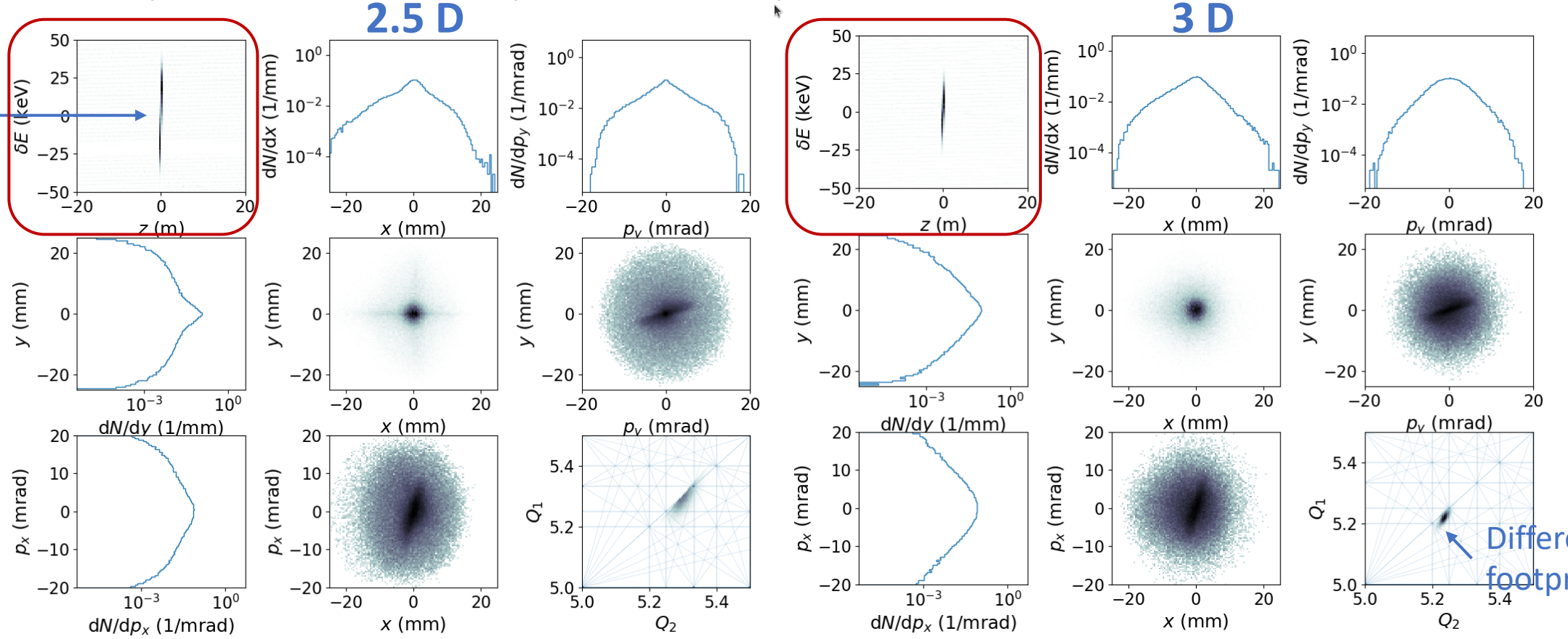


~80 times slower!!

Longitudinal kicks help in de-bunching the beam and reduces transverse blow-up.

Comparison of phase-space after 2000 turns

Larger energy spread

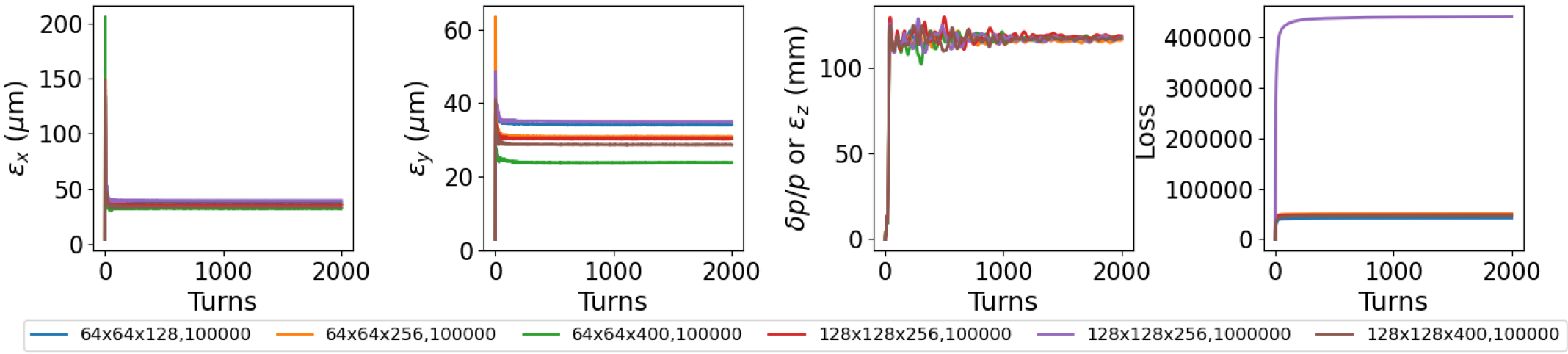


Different tune footprint

De-bunching is much slower compared to bare lattice!

3D more trustworthy?

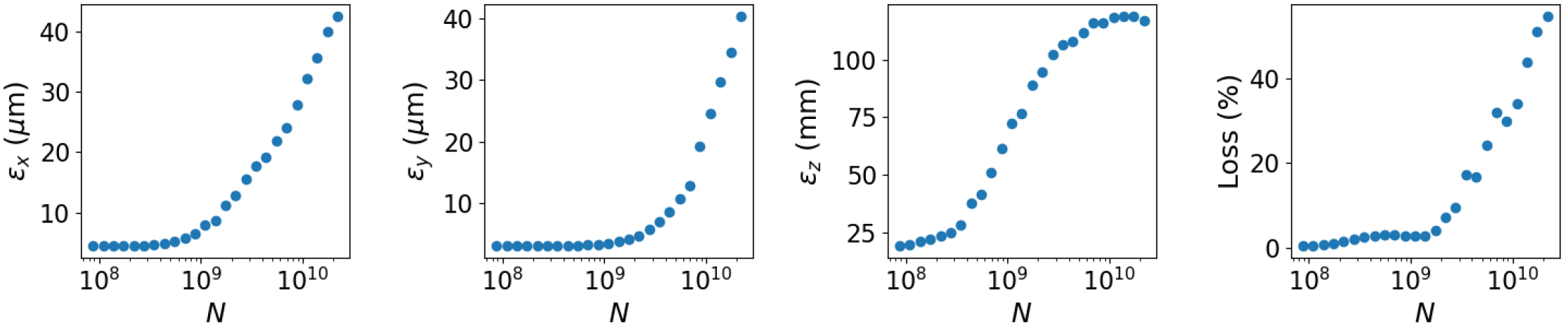
Convergence for 2.5 D simulations



- Decided to study convergence with the `SpaceChargeCalc2p5Drb` model since it's reasonably quick.
- Chose a grid size of 128x128x400 with 10^5 particles.

Injection with different intensities

Beam emittance and loss after 2000 turns using the `SpaceChargeCalc2p5Drb` model with a grid size of 128x128x400 and 10^5 particles



We should be able to inject 10^9 protons into IOTA without much emittance degradation.

Next Steps

- Explain why is the de-bunching time scale much longer with space-charge. Is this physically accurate?
- Talk to Eric Stern? Others?
- Do injection studies using the full 3D PIC model and estimate “realistic” beam parameters after injection. Document!!
- Add adiabatic capture for bunched beam.
- Study injection in other high-intensity accelerators and compare to IOTA.
- Can RF manipulations help?