Space Charge Benchmarks with Synergia

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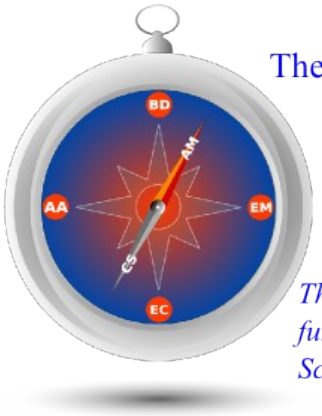

The ComPASS Project

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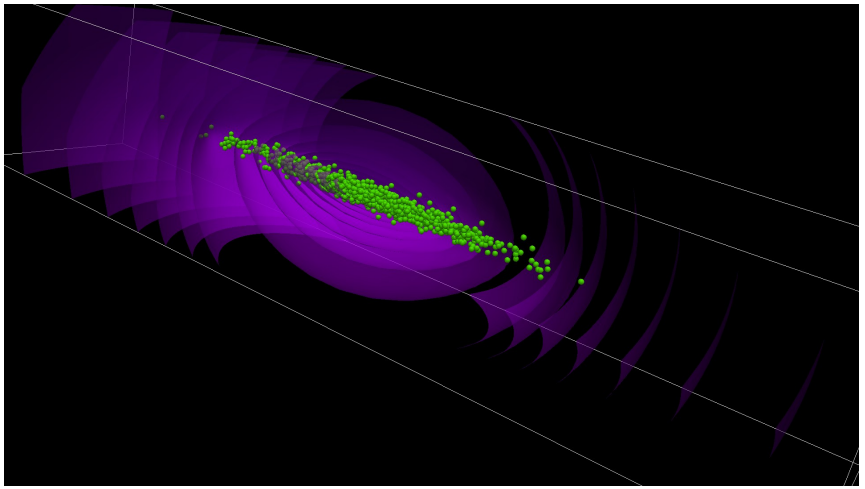
Fermilab



Space Charge will affect or limit operations

We need to be able to:
A) Simulate the effects of space charge
B) Simulate effects for long time periods
C) Simulate space charge effects on other accelerator dynamics
D) Know that they are correct

Space charge induced resonance trapping is an ideal testbed for space charge simulations.

Space charge induced resonance trapping: physics

Space charge and octupole driven resonance trapping observed at the CERN Proton Synchrotron, G. Franchetti and I. Hofmann, M. Giovannozzi, M. Martini, and E. Metral, PRST-AB **6**, 124201 (2003)

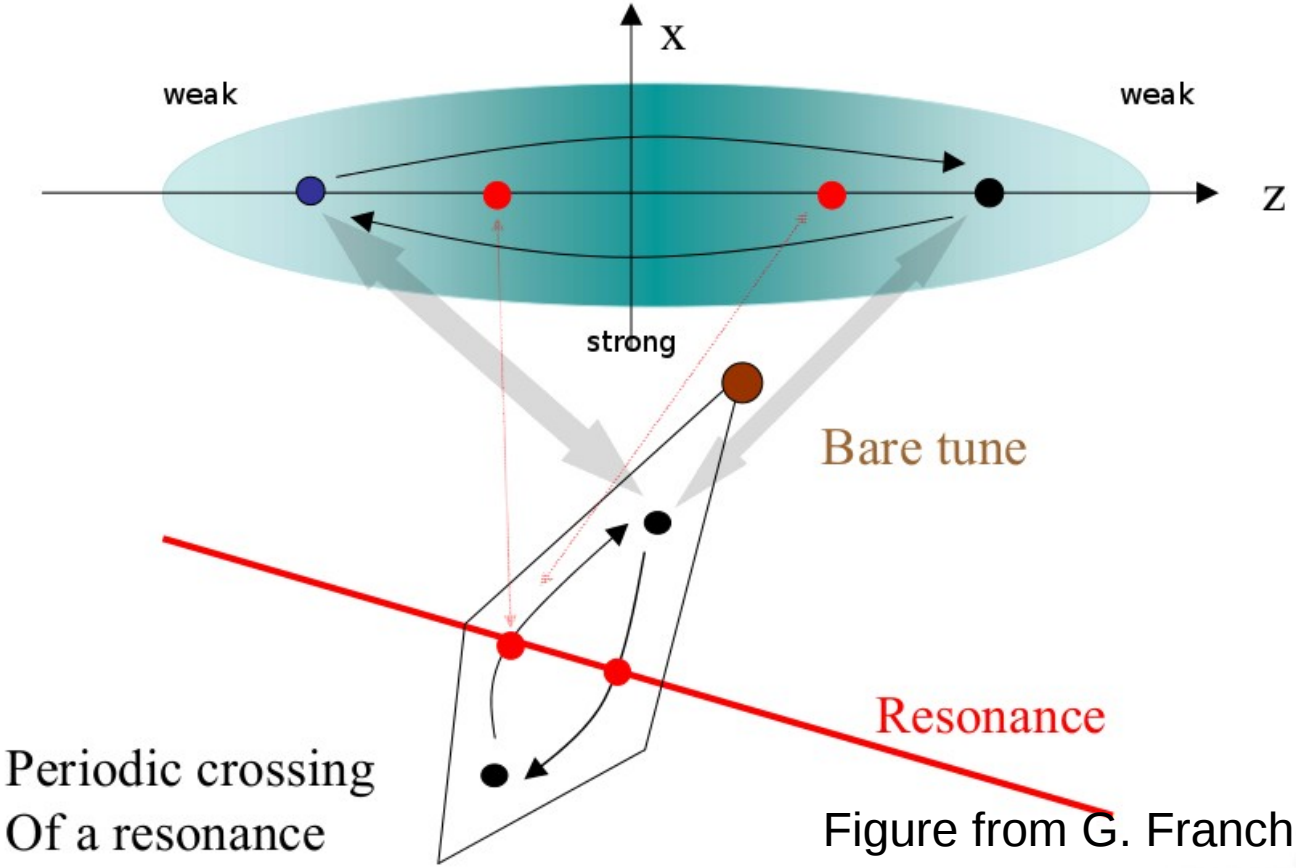


Figure from G. Franchetti, IPAC2006

Space charge trapping benchmark

- Space Charge trapping benchmark in GSI SIS18
  - http://web-docs.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html
- *The aim of the code benchmarking is to confirm the space charge induced trapping of particles in a bunch during long term storage.*

Simulation of resonance trapping is a good benchmark of simulation codes because it tests:

- Nonlinear transverse dynamics
- Long term tracking/longitudinal motion
- Space charge simulation

Simulate: Synergia

Developed by the Accelerator Simulation group within Fermilab's Scientific Computing Division: J. Amundson, P. Lebrun, A. Macridin, L. Michelotti, C.S. Park, P. Spentzouris, E. Stern

Particle-in-cell accelerator simulation
self-consistent code

- Independent-particle physics
  - Magnets, RF Cavities
  - Drifts
  - Apertures
  - Septa
- Collective Effects
  - Space Charge
  - Impedance

Synergia

- Symplectic particle tracking through elements provided by CHEF
  - Physics model is switchable on a per-element basis
  - Analysis through arbitrary order polynomial expansion

- Space charge models/boundary conditions
  - 3D open transverse boundary
    - Hockney with open or periodic longitudinal
  - 3D Rectangular conducting transverse boundary
    - Periodic longitudinally
  - 2.5D open boundary
    - 2D scaled longitudinal modulation by density
  - 2D semi-analytic Bassetti-Erskine
    - Force calculated analytically from 2^{nd} moments

  - Calculations are self-consistent. Fields reflect current charge density.

Synergia flexibility

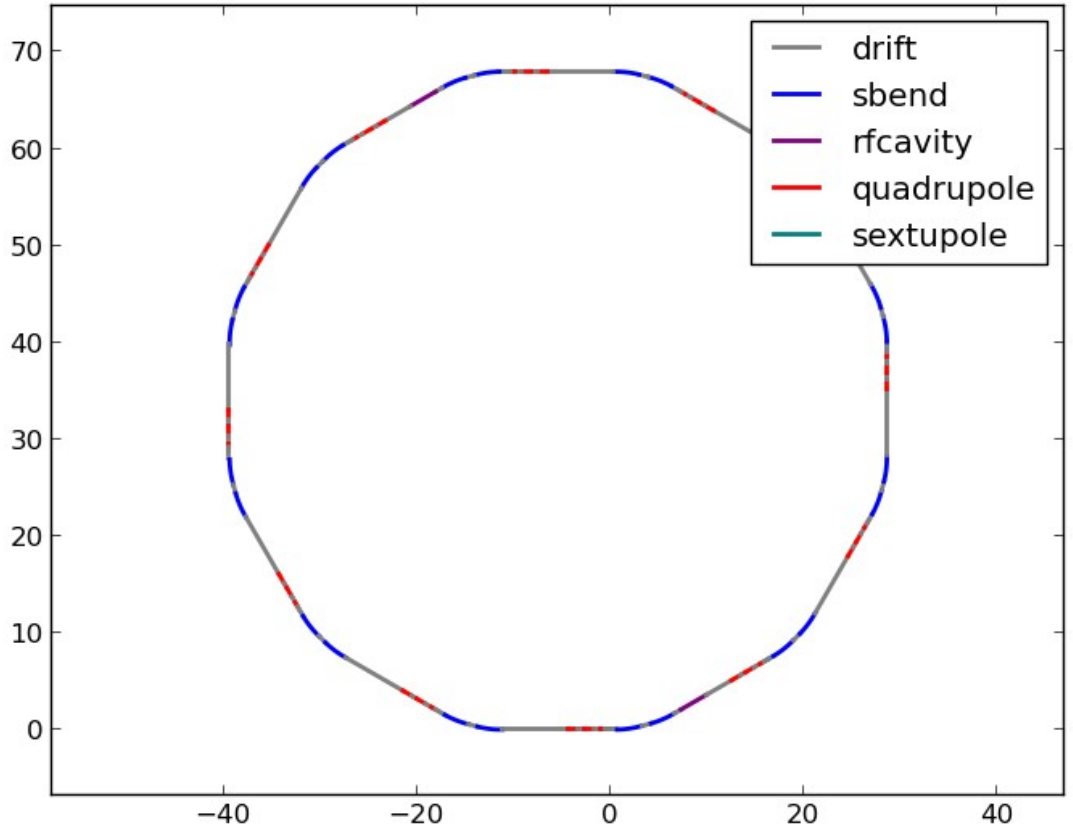
- Synergia runs on a wide range of computing hardware from laptops/desktops to department clusters to supercomputers.




- Simulations are typically python scripts giving full program control over the course of the simulation, allowing mid-execution changes to any of the conditions.

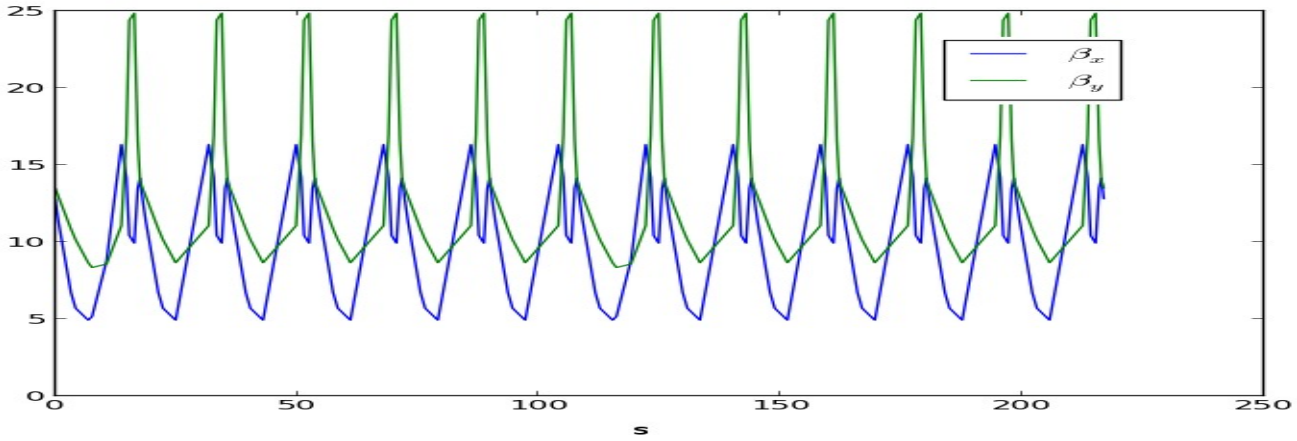
  - Synergia aims to provide the “best” algorithm for all aspects of a simulation tailored to your specific problem.

SIS18 Space charge benchmark



length	216.72 m
momentum	0.147 *GeV/c*
Beam σ_x	6.34 mm
Beam σ_y	5.60 mm
Beam σ_z	38.87 m
Qx	4.3506
Qy	3.200
Qs	1/15000
ΔQx	0.1

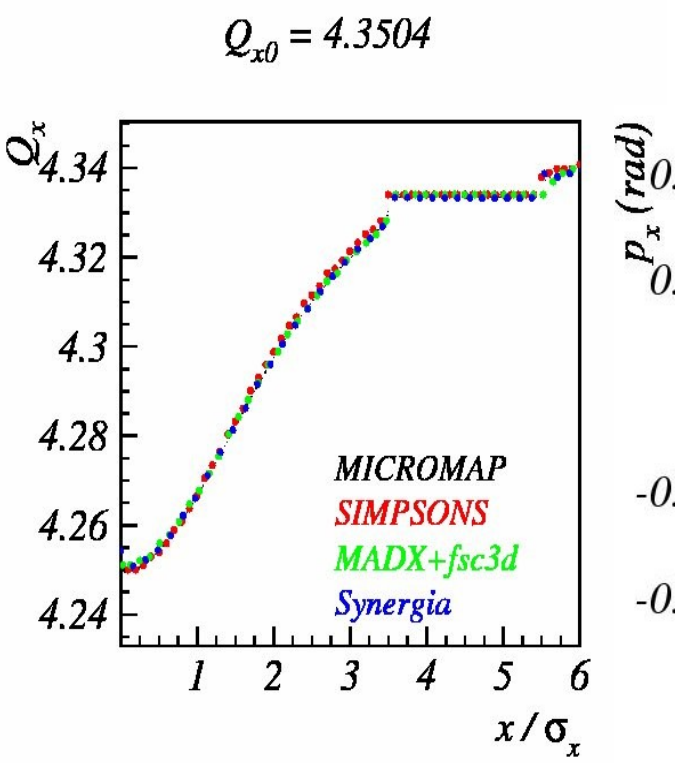
- Lattice has a sextupole
- Bunch is long: 2.5D solver is a good approximation



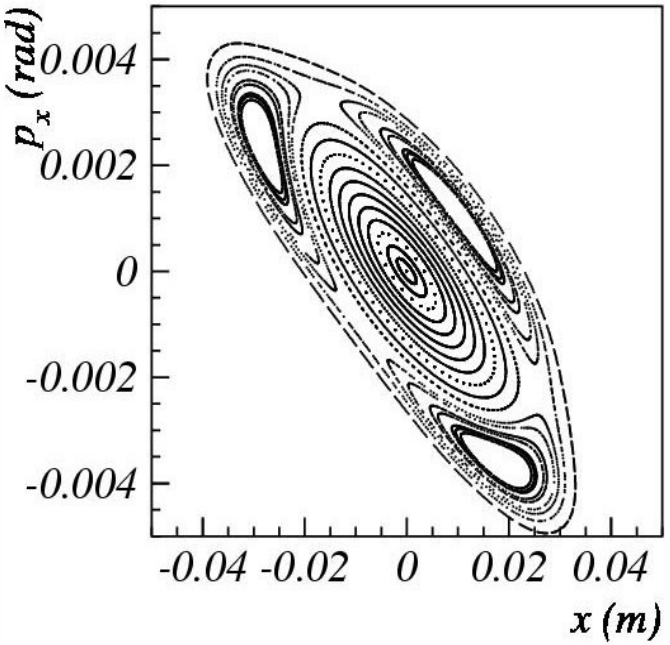
SIS18 phase space works

Follow test 50 particles at initial offsets from 0.0 to 5σ

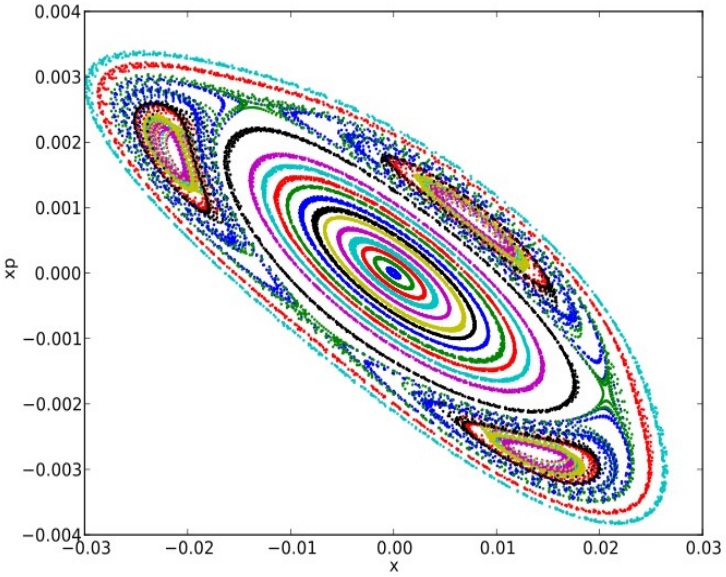
Tune vs. offset



Benchmark Phase Space

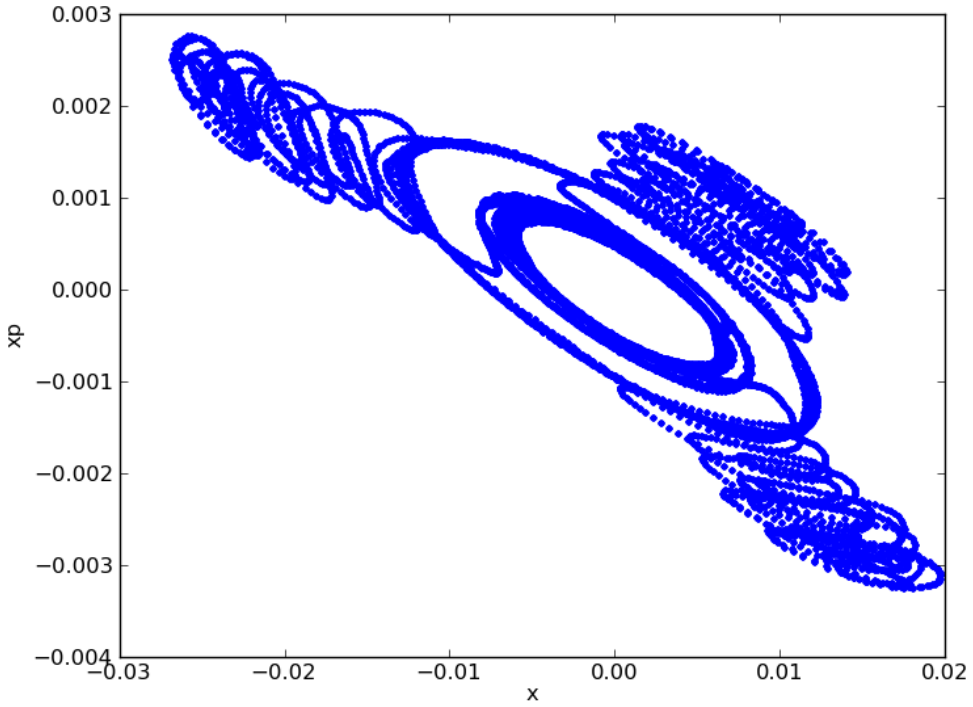


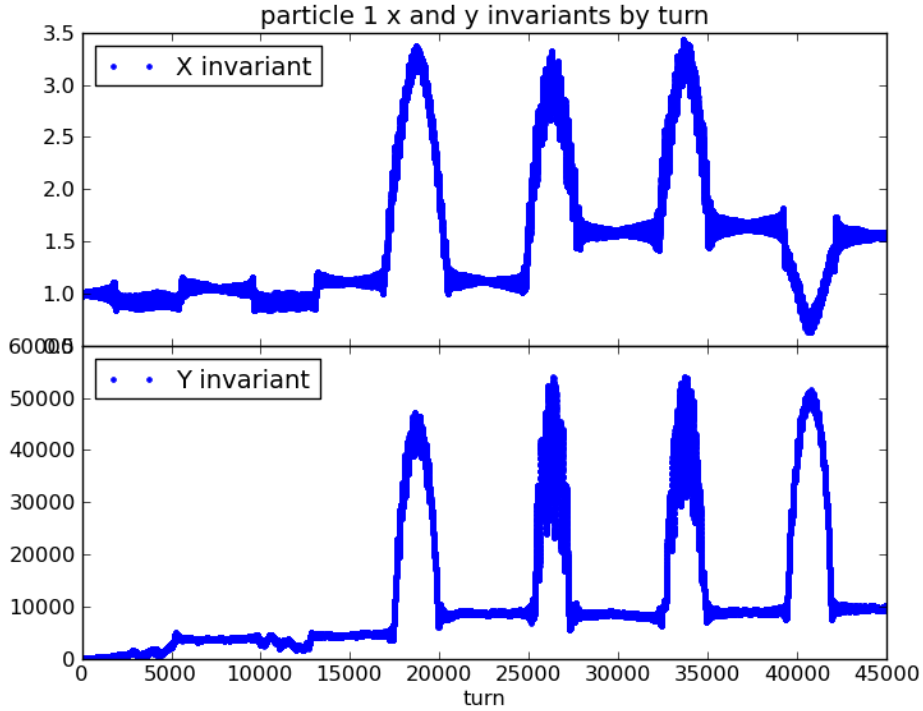
Synergia Phase Space



Synergia long term tracking

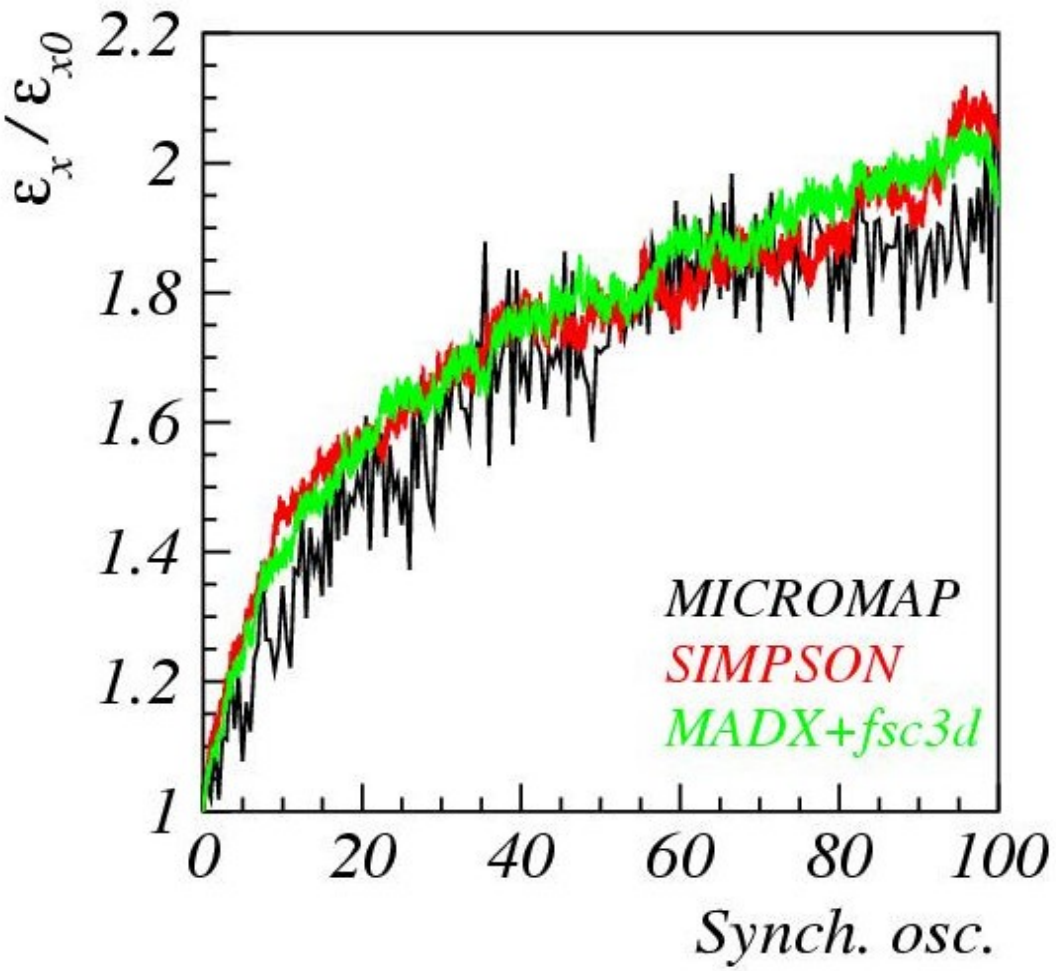
Single particle trapping

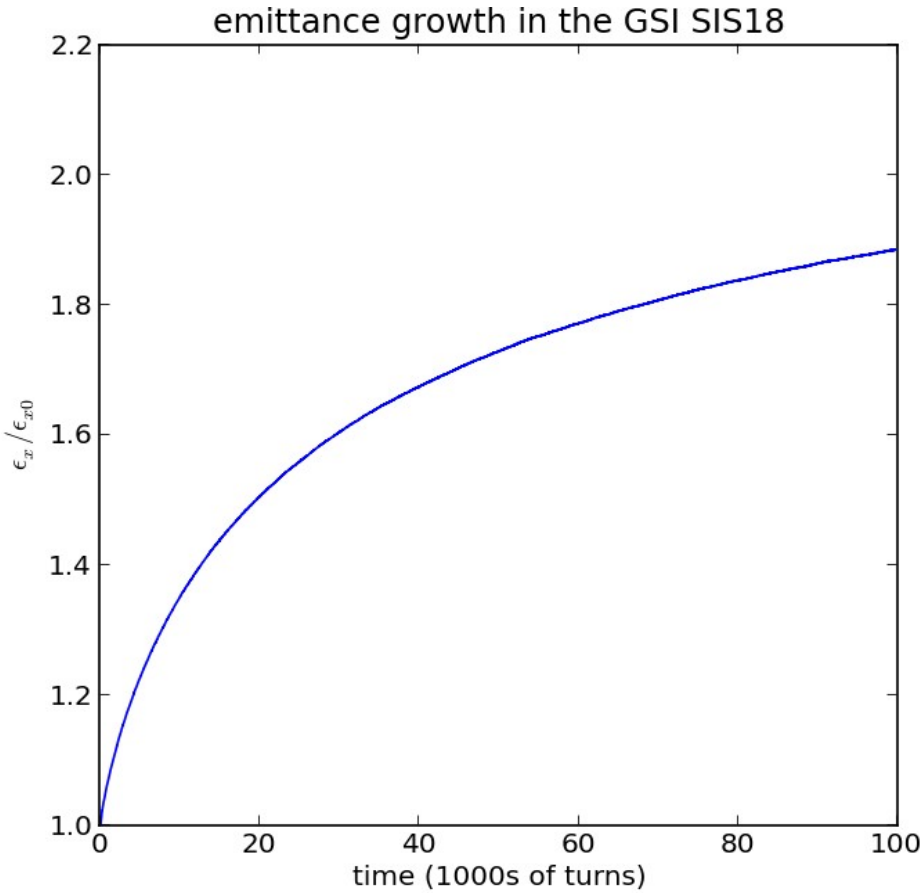




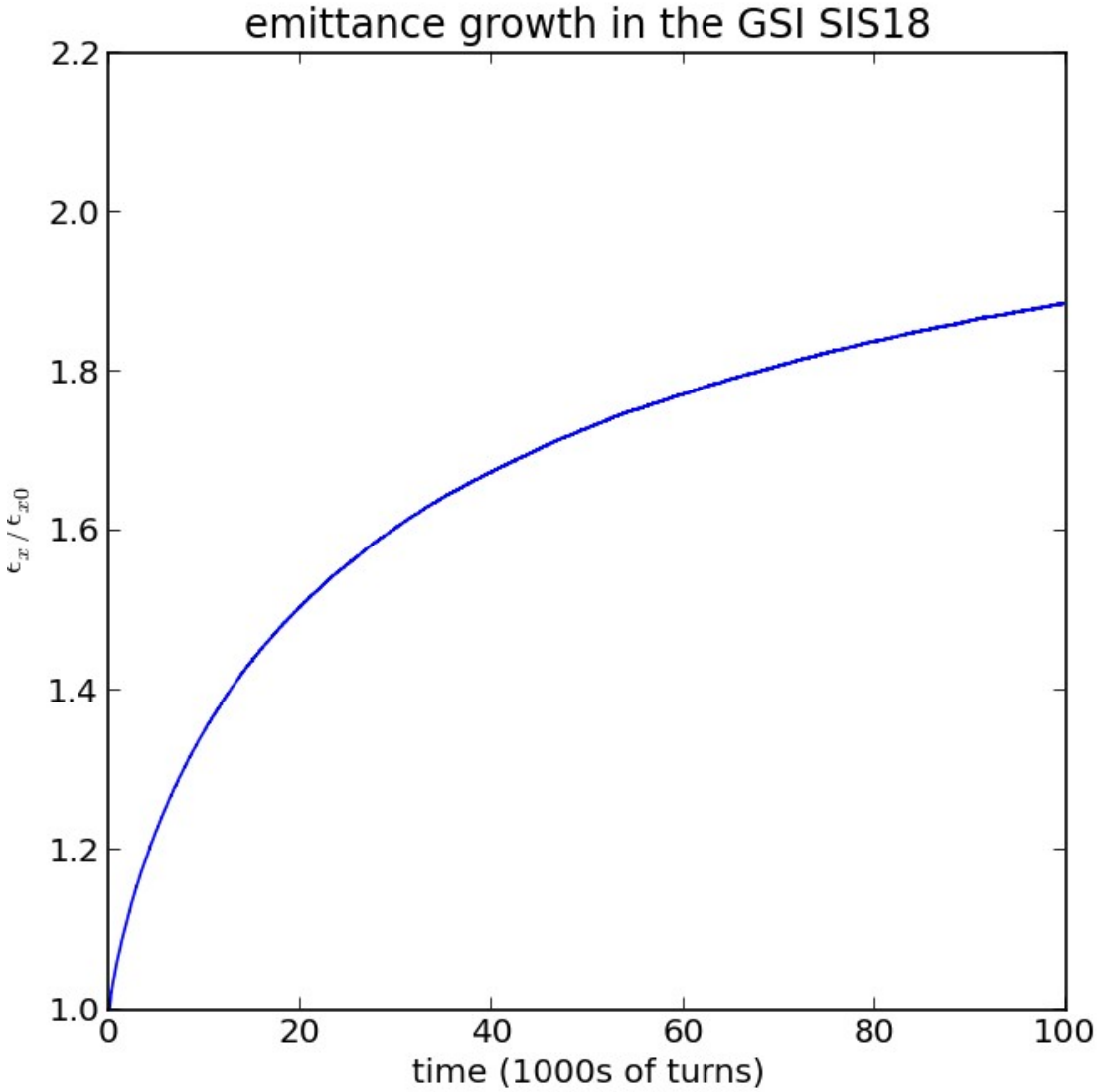
Synergia emittance growth

Synergia 4M macro particles





Synergia really big PIC simulation



- 100,000 turns
- 71 steps/turn
- 7,100,000 steps (SC solves)
- 4,194,304 macro particles
- 29,779,558,400,000 particle-steps

Largest PIC beam dynamics simulation ever

Conclusions

- We have shown that Synergia space charge simulations of a complicated beamline demonstrate detailed features of space charge interaction with dynamics.
- We have performed the largest ever self-consistent beam dynamics PIC simulation with Synergia. Synergia simulation remains stable with large number of turns.
- Synergia is unmatched in its ability to do long-term detailed multiple dynamics PIC simulations.