Beam Dynamics in IOTA using PyORBIT

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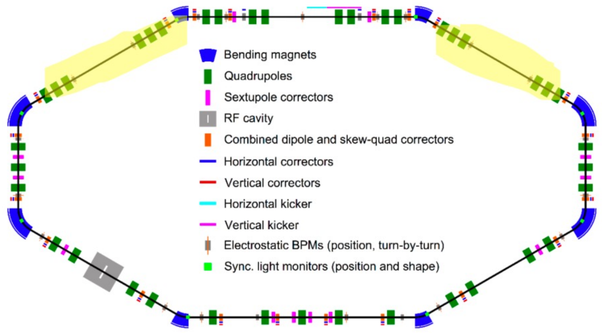
Integrable Optics Test Accelerator (IOTA)

- Storage ring for advanced beam physics
- Stores proton and electron beams
- Currently running experiments with electrons
- Small and can be easily reconfigured to accommodate a wide-ranging experimental program



IOTA Schematic

Space Charge Force

- Self generated electro-magnetic force
- Net repulsive
- While negligible in beams where particles move at highly relativistic velocities. not the case for the proton beam in IOTA

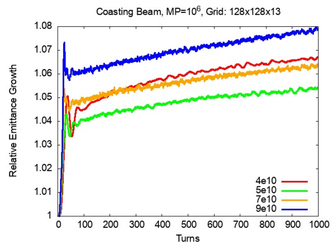
$$F = \frac{e^2 N}{2\pi\epsilon_0 r \gamma^2}$$

- The transverse force for a uniformly charged cylindrical beam distribution is shown above
- Perveance is the magnitude of the space charge force in the beam. It is proportional to Q / β*γ^2
- Beam distribution impacts the space charge effect
- A mismatch between the incoming beam and lattice matched beam results in increased field energy which converts to emittance growth

IOTA Proton Beam Parameters

Parameter	Value
Beam Kinetic Energy, E	2.5 MeV
Beam Intensity, N	9 x 10^{10}
Normalized Emittance, ε	0.3 μm
Tune Shift (coasting, bunched)	-0.5, -1.2
Space Charge Perveance (coasting, bunched)	1.3 x 10^{-6}, 6.06 x 10^{-6}

- Emittance growth is significantly reduced for the coasting beam as the perveance is about 5 times smaller



Integrable Optics

- Space charge defocusses the beam, causing tune spread to grow and particles to hit resonances and get lost
- Integrable optics might remedy this by suppressing single particle resonances with a nonlinear focusing force
- Full integrability can be achieved with specially profiled nonlinear magnets and partial integrability can be achieved with a sequence of conventional octupole magnets
- Integrability is a property of single particle motion, and space charge introduces a perturbation that has the potential to destroy the favorable features of integrability

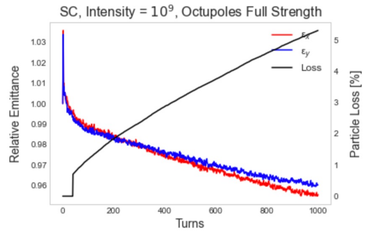
Purpose of Project

- The goal of the project is to test if these optics can mitigate space charge driven resonances and retain the benefits of integrability while keeping loss at an acceptable level
- Simulations are performed with PyORBIT, a PIC code for multi-particle tracking that models space charge effects

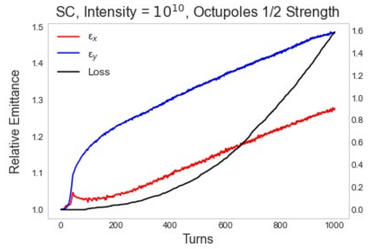
Methods

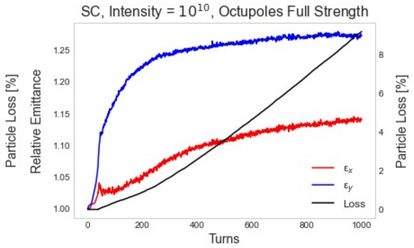
- Particles are tracked for 1000 turns about the IOTA lattice
- Simulations have examined a bunched beam with octupoles at various strengths for reduced and full beam intensities

Results

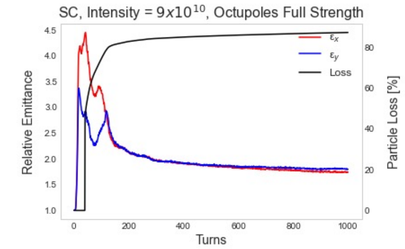


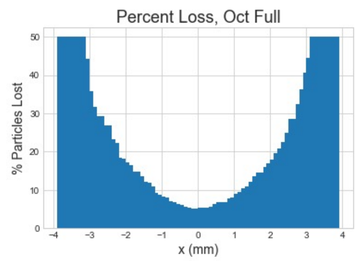
- Even at a low intensity, the space charge force moves particles past the small dynamic aperture caused by full strength octupoles
- An attempt to account for this was made at a greater intensity by truncating the initial particle distribution:





- At full intensity, space charge results in >80% loss at full strength, even with a truncated Gaussian distribution





- Data from 1e10 intensity verifies that particles are more likely to hit the DA if they are initialized further from the beam center

Conclusions

- Due to DA reductions, partial integrability does not seem to withstand a large space charge perturbation well
- Integrability is sensitive to certain lattice specific properties, such as the phase advance outside of the nonlinear insert, which will be investigated
- Further work includes testing a uniform (as opposed to Gaussian) distribution and rematching the beam to a phase advance of 2π with space charge

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