Vlasov Project 4D Code Development

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Introduction

This summer we hoped to continue research that we began last summer to create (or get as close to as possible to creating) a numerical Vlasov Solver. The Vlasov equation is a PDE that gives the momentum and position of particles as time changes. Depending on the data collected from detectors, the configuration of magnets in an accelerator can be changed to better mitigate instabilities and other noise affecting the beam.

This couples well with the IOTA accelerator at Fermilab because the configuration of IOTA can be changed with minimal cost and downtime; versus larger accelerators which takes weeks or months of downtime to reconfigure.

Movement through an accelerator can only occur with charged particles. The particles can be either negatively charged or positively charged. The charged particles create an electromagnetic field which affects the two directions that are transverse to the direction of the movement of the charged particles. The 'noise' that the PIC (particle in cell) codes are affected by is usually referred to as space charge.

Space charge is caused by the repulsive force between the like charged particles moving through an accelerator. Particles that are being affected by space charge are pushed away from each other and leads to the beam being degraded by the lose of some particles to the pipe wall. The increase in halo size of the beam is the phenomena known as emittance growth and can cause instability in the beam line which needs to be avoided as much as possible.

Previous Work

Our original goals for the collaboration with Fermilab was to study space charge effects in IOTA with a numerical Vlasov solver which we had hoped to develop during this program. The Vlasov solver would have been used to calculate emittance growth, halo development, possible instabilities and their mitigation under a variety of beam conditions in IOTA.

Last summer, we were able to devise a 2D code to track particles through an idealized accelerator as well as a 2D code to calculate the density distribution of the particles through the accelerator. 2D as in position and momentum of the particles in only one transverse direction, the x-direction.

This summer, we were able to upgrade both the particle tracking code and the density distribution code to 4D which now includes the 2^{nd} transverse direction in the y-direction.

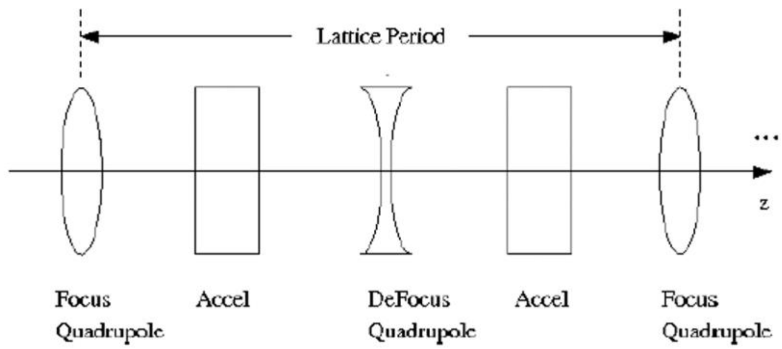
Priorities

1. Our priorities were to maintain the conservation of the emittance of the system. Emittance is the area of the beam cloud and determines if the beam reaches its destination without breaking up or being lost.
2. We also strived to maintain the density of the system throughout the accelerator A change in the density would mean that particles were being lost to the walls in the accelerator.
3. Also, increasing the efficiency of the code to cut down on processing times was also a focus this summer.

Methods Used

Methods used were the same as last year for the idealized accelerator used in the 2D system but now written with a 4D variable model. The equations can be updated to the 4D model by switching out the 2D X which was (x, x') for the 4D X which now stands for (x, x', y, y') to represent both the transverse directions. A reference/starting point was maintained at position O and then the particles would encounter a "kick" at position P 90^{o} downstream.

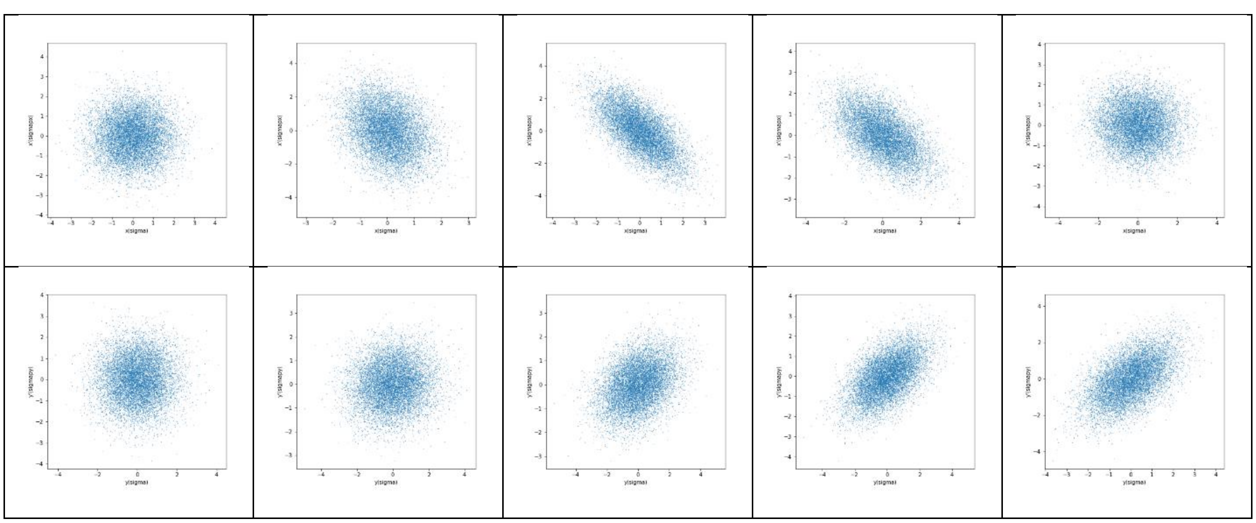
The figure below shows an ideal arrangement of the focusing and defocusing quadruple magnets separated by drift spaces of a certain length that create an 'ideal' FODO lattice arrangement used in this exploration. The drift spaces are where the magnets used for bending (dipoles, sextupoles, etc) and RF cavities for accelerating the beam are located.



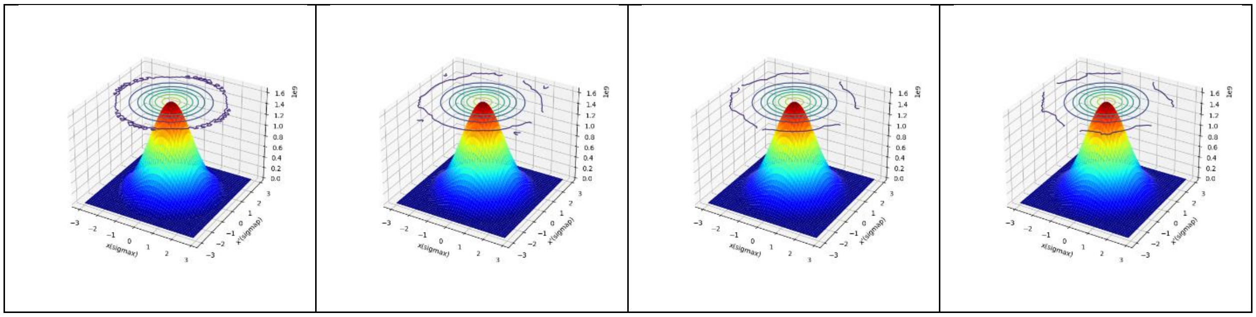
The quadrupole being used is thin enough to be considered a thin lens quadrupole so the focal length can be found easily. This thin lens approximation implies that the length of the magnet is short enough that the displacement through the accelerator is unchanged as the particle passes through the magnet guaranteeing a constant magnetic field along the particle's path.

Results

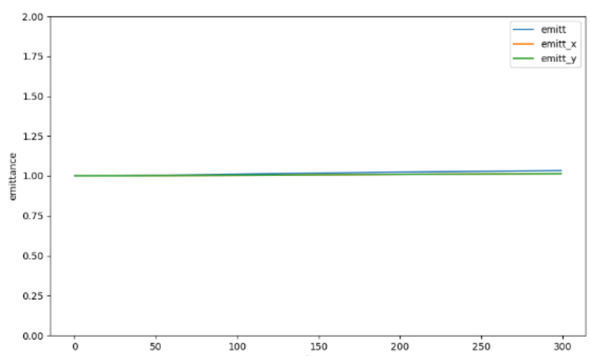
1. We investigated changing the perturbation at position P from a sextupole to a skew quadrupole to help mitigate the coupling that can occur with interactions between the transverse directions. We still need to investigate how to involve the transfer matrix of the skew quadrupole into the 4D code.
2. The accelerator 4D particle distribution of a simulated 10,000 particles through 10,000 turns was successfully mapped as shown below in the figures taken every 2000 turns through the accelerator. The rotation of the articles in both x and y transverse directions can clearly be seen.



3. The output from the 4D density distribution is shown in the array of figures below. The figures start at the initial x- and y-position and are captured at 100, 200, and then at 280 turns.



4. The conservation of the emittance in the 4D code is still being investigated which is largely impacted by the density distribution of the system. The following figure shows the emittance from the density distribution program. There should be some wavering for the x and y emittance but they both stay very close to 1, the overall system emittance. We are still looking for any possible errors in the way the emittance was calculated.



5. Parallel computing through the use of the open source MPI was incorporated into the density distribution code but even with that, a small number of turns through the accelerator still takes upwards to a half a day of computing power to accomplish.

Next Steps

The next steps in the project is to continue to integrate the use of parallel computing schemes to increase the speed of the density distribution program while still striving to conserve the emittance and density of the system.

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