Vlasov Project: 4D Code Development

FERMILAB-POSTER-23-188-STUDENT

Demetric Baines, Yonghua Yan, Jackson State University; Tanaji Sen and Jean-Francois Ostiguy, Fermilab AD

Introduction and Purpose

A Vlasov-Poisson solver together with experimental tests done with Fermilab's IOTA (Integrable Operable Test Accelerator) will be very useful in improving the accelerator beam intensity, quality and prediction. The need for such a code has long been noted in the beam dynamics community.

Continuing from the work started last year with the development of a 2D particle tracker and 2D density distribution program, we continue and proceed in the development of a 4D particle tracker and 4D density distribution program. The conservation of the system's emittance and density will be investigated.

Methods Used

Continuing work started last year, four dimensions were represented in both the x and y directions consisted of the particle distance from the point of reference and its momentum.

The methods and equations used last year for the 2D case can be updated to apply to the 4D case by switching out the 2D X which was (x, x') for the 4D X which now stands for (x, x', y, y').

The particles were mapped and the density distribution were then defined and analyzed using the open source programming language Python.

The transfer matrix for the sextupole:

$$M_{sext}(X) = (x, x^2) + (0, k_2 x^2)$$

The initial position of the particles is at position O. The position P is where the sextupole is located.

The transfer map used to track the particles:

$$X_{n+1} \equiv T[X_n] = M_{PO} * M_{sext} * M_{OP}(x, x')_n^T$$

The beam density is transported by the inverse map:

$$\rho_{n+1} = \rho(T^{-1}[X_n])$$

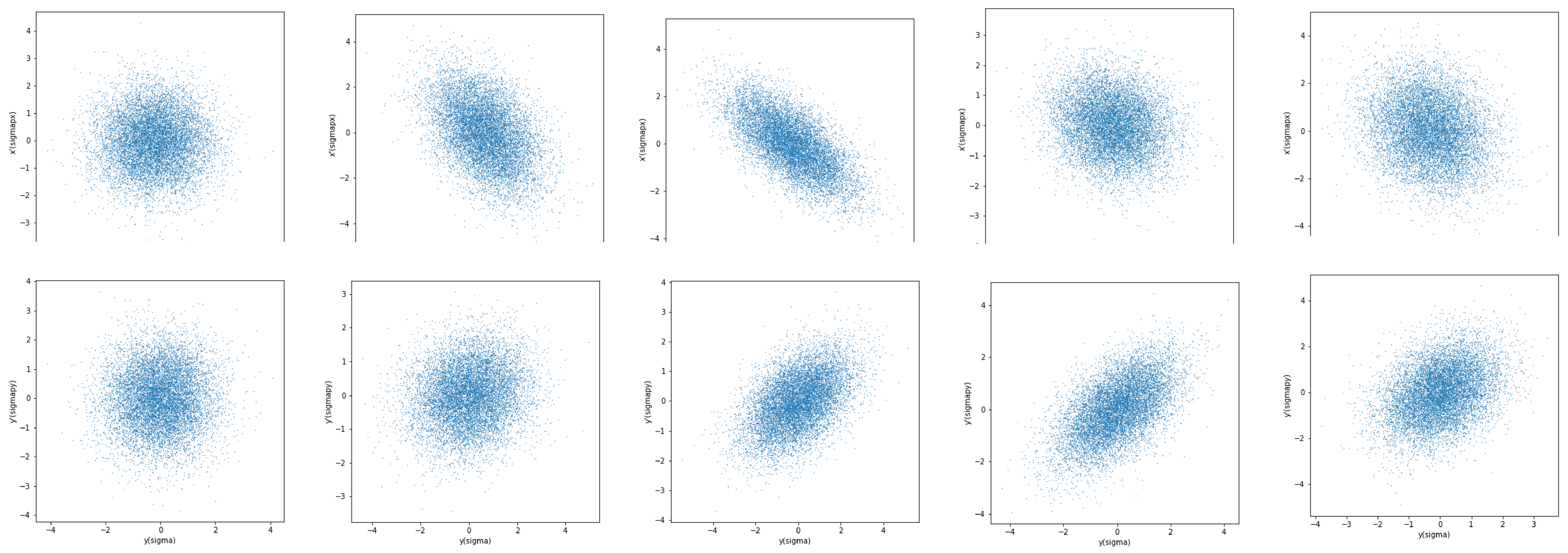
$$T^{-1}[X_n] = M_{OP}^{-1} \cdot M_{sext}^{-1} \cdot M_{PO}^{-1}\, X_n$$

$$M_{sext}^{-1} = X - \Delta X$$

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.
This work was supported in part by the U. S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Visiting Faculty Program (VFP).

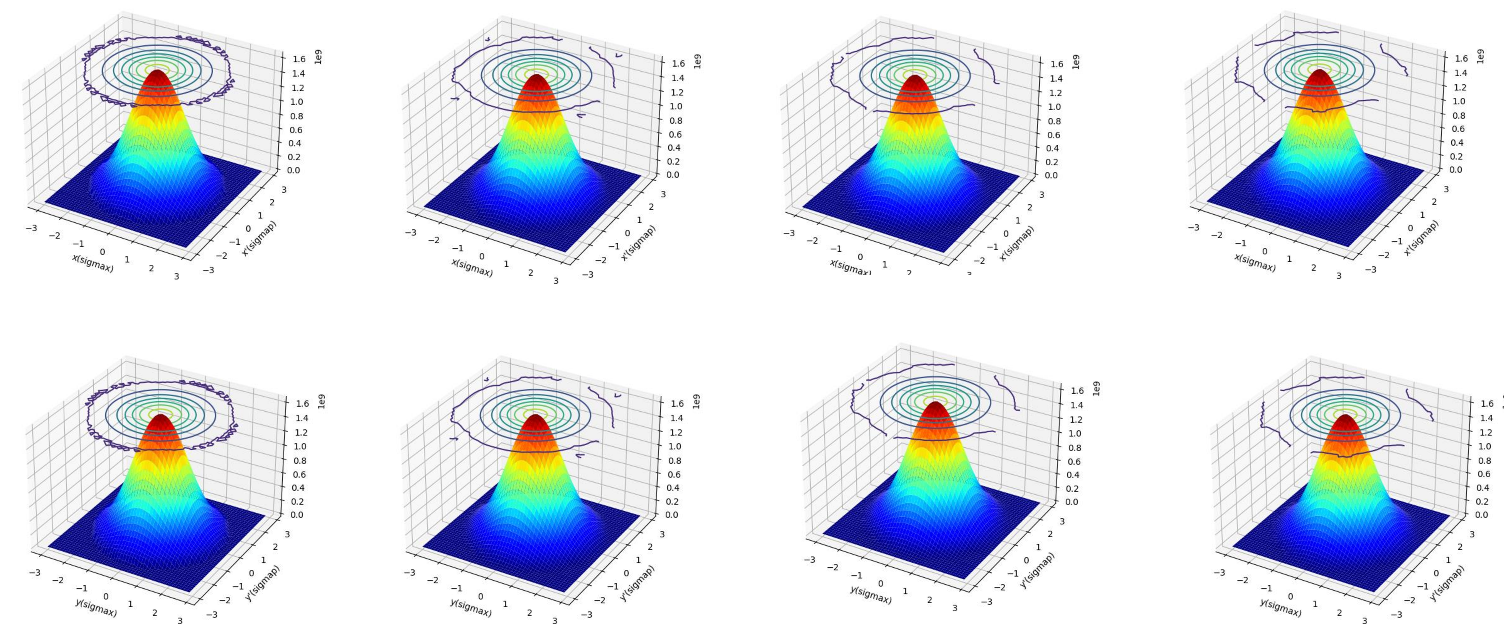
Conclusions and Future Work

The accelerator 4D particle distribution of a simulated 10000 particles through 10000 turns was successfully mapped as shown below in the figures taken every 2000 turns. The rotation of the particles in the accelerator can be clearly seen as one advances through the figures.

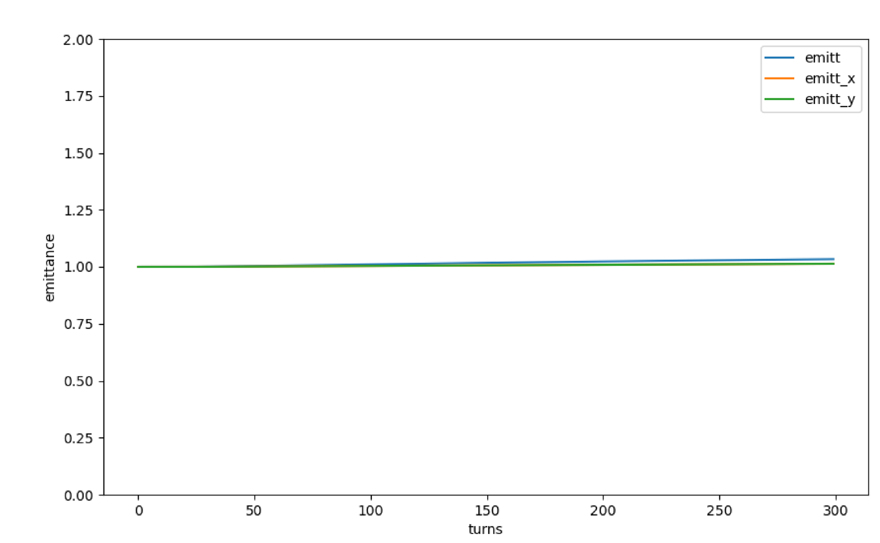


Accelerator particle distribution from initial position to the 10,000th turn through the accelerator.

The output from the 4D density 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.



Density distribution of the particles in both the x- and y-positions at different turns.



System emittance.

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.

References

1) D. A. Edwards and M. J. Syphers, An Introduction to the Physics of High Energy Accelerators, John Wiley & Sons, 1993.

2) S.K. Dutt, et al, "Direct Simulation of Beam Density Evolution in Phase Space: Preliminary Modeling in One Degree of Freedom", Advanced Beam Dynamics Workshop, October 1991.

3) S.M. Lund, Transverse Particle Dynamics, USPAS Summer Session, Northern Illinois University, June 2017