Simulations of an Electron Lens in IOTA

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Abstract

An electron lens is an element of a particle accelerator lattice which generates an electromagnetic field by creating a beam of low-energy electrons. This negatively charged beam should match the positively charged proton beam circulating the accelerator in an attempt to improve beam stability. We simulate the impacts of an electron lens using Synergia, a 6D particle accelerator simulator capable of simulating collective effects. We simulated an electron lens in the IOTA (Integrable Optics Test Accelerator), a storage ring under construction at Fermilab.

Introduction

There are three main parts to the simulation process:

- **IOTA:**
  - Experimental test ring
  - Low-beta protons at 2.5 GeV
  - ~40 m circumference
- **Electron Lens:**
  - Non-linear element
  - Radially symmetric (focuses evenly)
  - Calculations show it should eliminate some space charge.
- **Synergia:**
  - Highly scalable and robust particle accelerator simulation technology
  - Accounts for collective effects
  - Pre-compiled C++ functions wrapped in Python

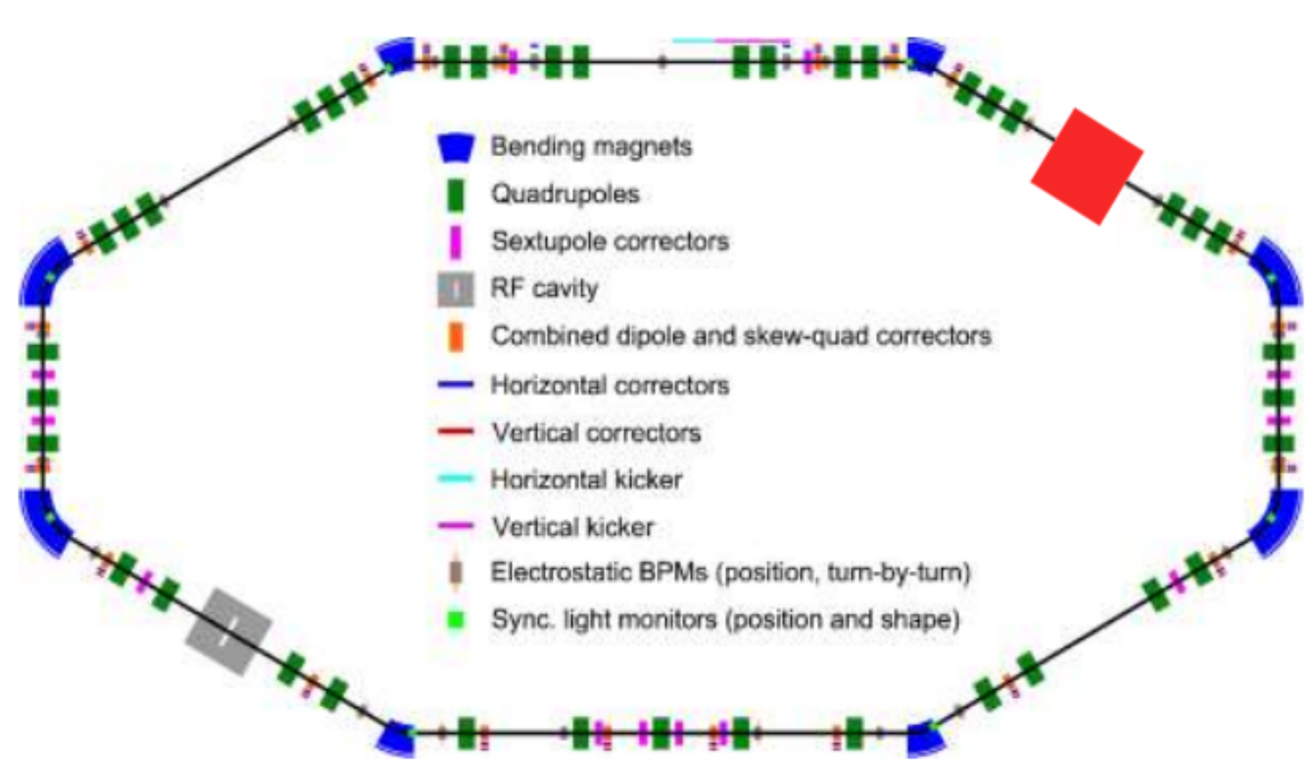


Figure 1: The IOTA lattice. In red is the area in which the electron lens is placed in our simulation. This is where the X and Y beta functions match.

Simulation Parameters

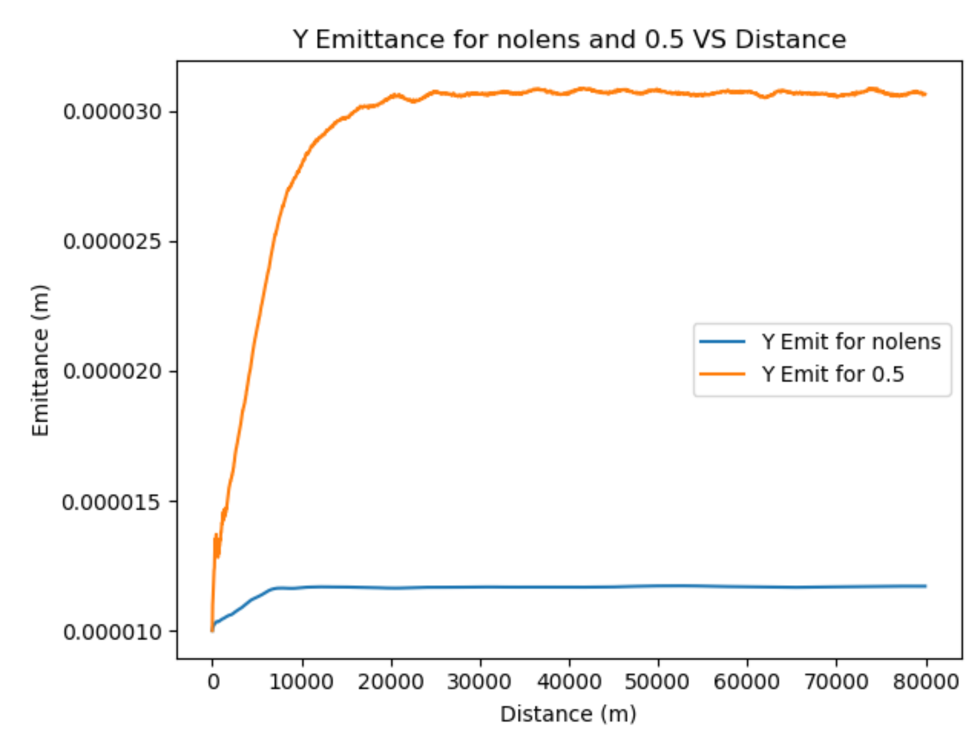
The parameters were initially derived from [1], an article about IOTA. These were taken and modified such that the ring's tune shift was less than 0.2. The electron lens was then set to match the proton beam parameters.

Simulation Parameters:

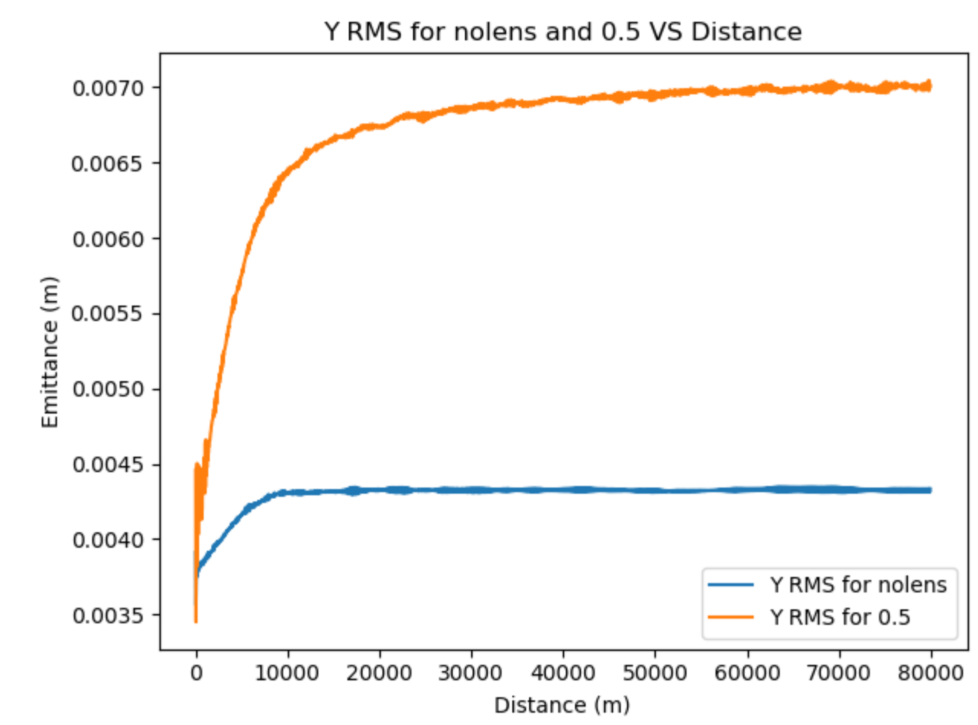
- Energy: 2.5 MeV
- Real Particles: 2.25E9
- Macroparticles: 1E5
- Emittance: 1E-5
- Bunch Length: 1.7 m
- Turns: 2,000

Results

We ran simulations with the above parameters and generated multiple graphs with Matplotlib.

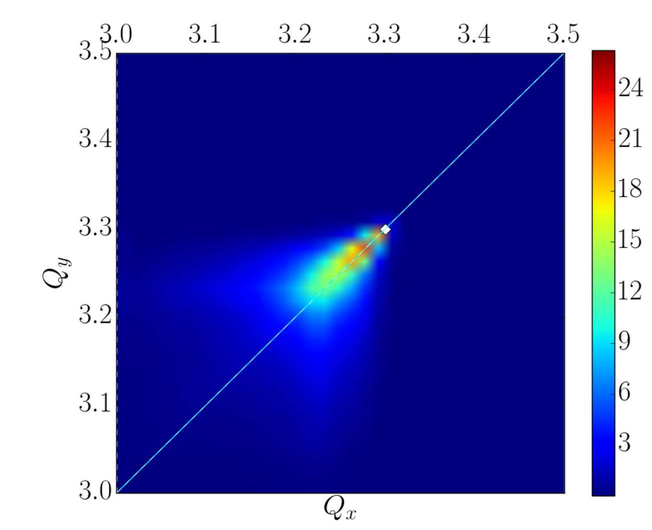


Plot 1: This shows the Y emittance vs. distance for a beam with no electron lens (blue), and for an electron lens (orange).

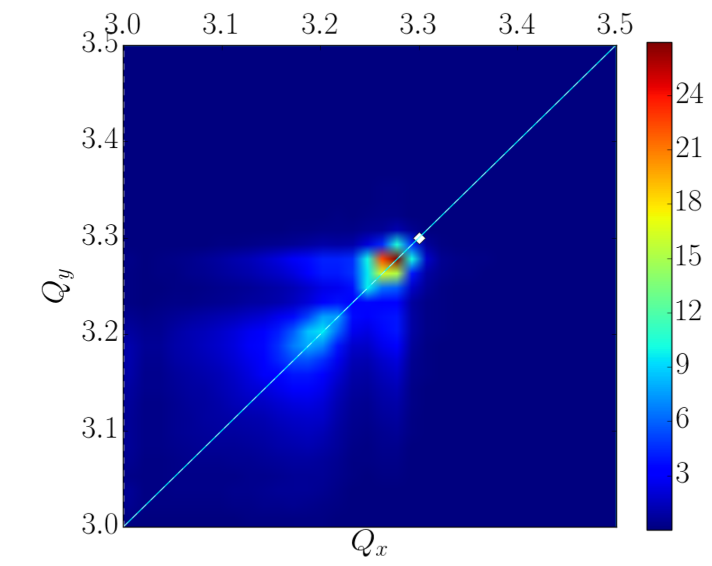


Plot 2: This shows the Y RMS vs. Distance for a beam with no electron lens (blue), and for an electron lens (orange).

Results (Cont.)



Plot 3: Tune footprint without the electron lens. The nominal tune is the white dot.



Plot 4: Tune footprint with the electron lens. We can observe that the electron lens gives a substantial tune shift.

A calculation in [2] by Eric Stern shows that our tune shift due to the electron lens should be .166, a fact verified by plots 3 and 4.

Conclusion

The hoped-for benefits in emittance growth and beam stability were not realized with our simple electron lens model. This is supported by our plots showing increased emittance and RMS. Our plots showing the tune spread of the electron lens verify that it is acting correctly.

Acknowledgments

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References

[1] Sergei Antipov, Vladimir Shiltsev et al. IOTA (Integrable Optics Test Accelerator): Facility and experimental beam physics program, 2016.

[2] Eric G. Stern. Momentum kick to a proton traversing an electron lens.

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