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Simulation of Relativistic Electrons Through a Magnetic Chicane

Matthias Fuchs
University of Nebraska-Lincoln, mfuchs@unl.edu

John Chrostek
University of Nebraska-Lincoln

Nathan W. Ray
University of Nebraska-Lincoln, nathan.ray@huskers.unl.edu

Jordan O'Neal
University of Nebraska-Lincoln

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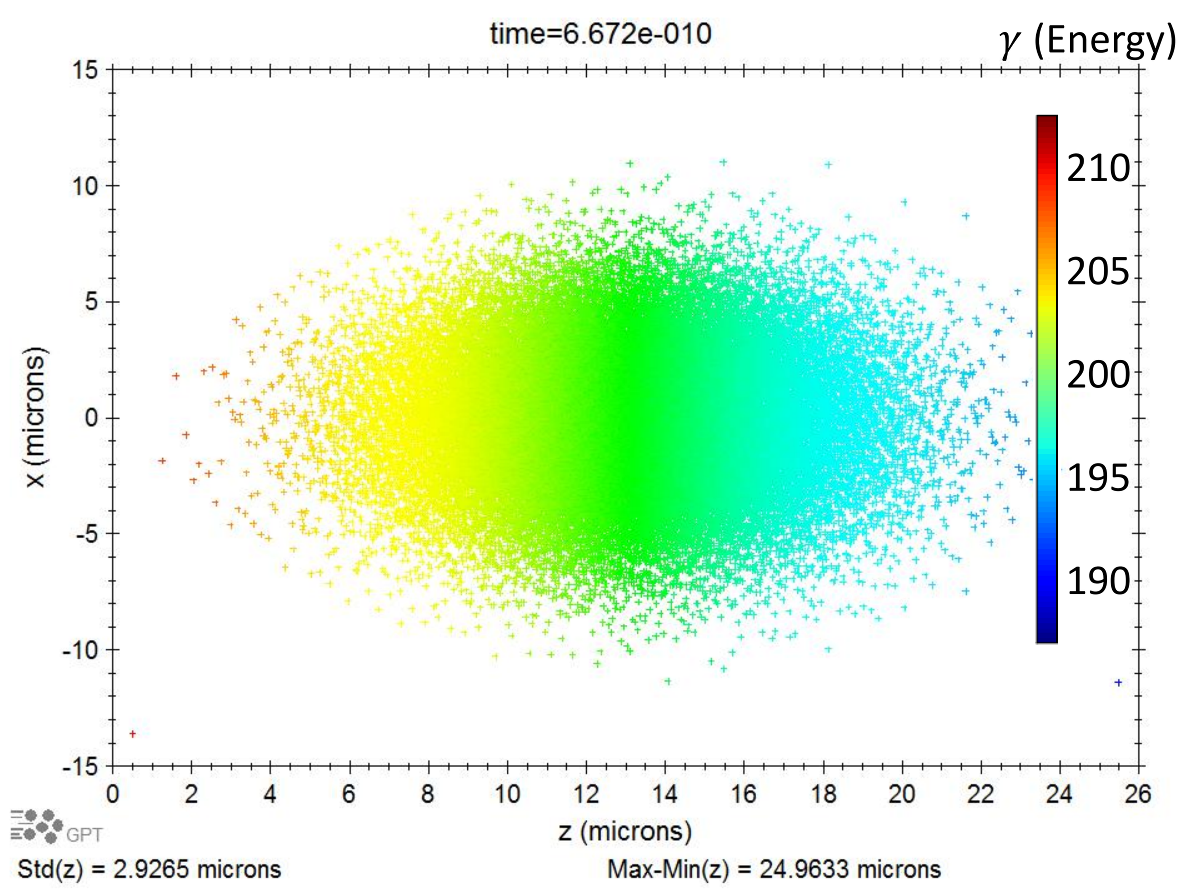
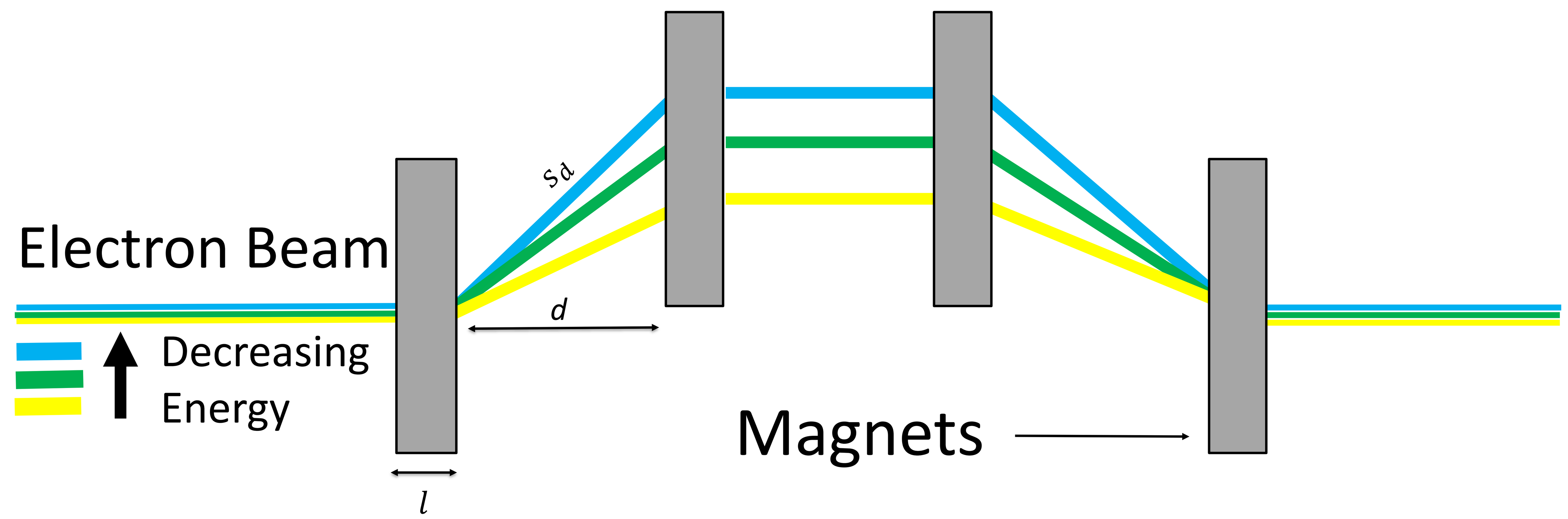
Group for Ultrafast and High-Field X-Ray Science, Physics Department

Dr. Matthias Fuchs, John Chrostek, Nathan Ray, and Jordan O'Neal

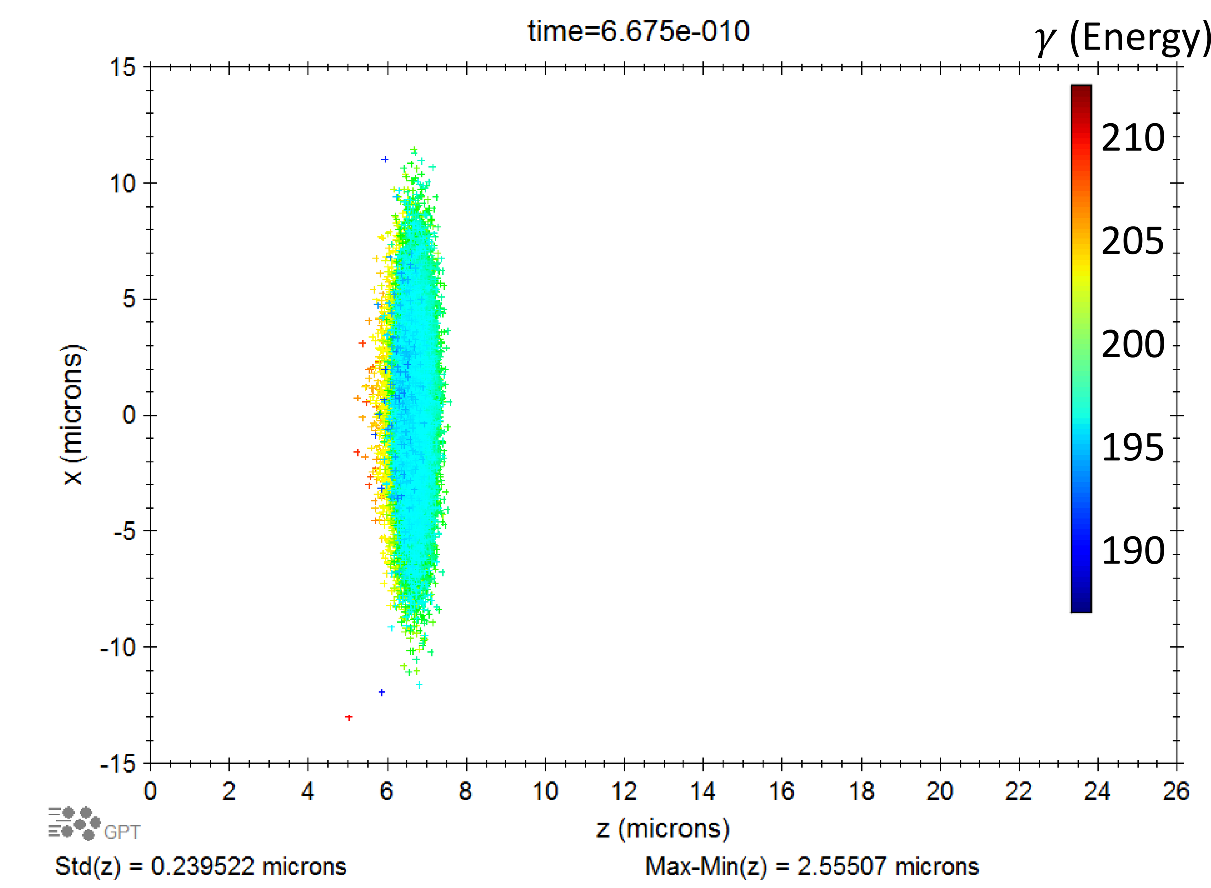
Electron Bunch Before Chicane



Chicane Depiction



Electron Bunch After Chicane



Background

- X-ray Free Electron Lasers (XFEL) use high power, short pulse laser beams to create a bunch of relativistic electrons.
- This bunch of relativistic electrons passes through an undulator to create x-rays, which have applications such as resolving molecular images.
- A shorter bunch of electrons results in better x-rays.
- It is possible to create a bunch such that electrons in the front of the bunch have less energy than electrons at the rear.
- Electrons traveling through a chicane travel different distances depending on their energy.
- A chicane will allow electrons at the back to catch up to electrons at the front, thus shortening the bunch.

Procedure

1. Review literature and derive formulas for the effect of a chicane on two electrons.
2. Use MATLAB to calculate the results for two electrons with different energy levels.
3. Use General Particle Tracer (GPT) to simulate a beam of electrons traveling through a chicane.
4. Compare simulated data with our theoretical calculatoins.

Theoretical Calculations

The path length of the electrons is composed of two parts:

1. In the magnet, electrons move in a circular path with radius r based on their energy which is reflected by the γ term.

$$r = \frac{mc}{qB}\sqrt{\gamma^2 - 1}$$

Taking into account the length of the magnet, l, we obtain a path length of

$$s_m = r * \arcsin\left(\frac{l}{r}\right)$$

2. Outside of the magnet, the paths lengths are determined by the angle the electrons makes when leaving the magnet, θ, and the magnet separation d.

$$s_d = \frac{d}{\cos(\theta)}$$

Combining the previous equations and accounting for the design of the chicane yields a total path length of

$$s = 4s_m + 2s_d + d$$

Since s_m is significantly smaller than s_d, and d is constant, we can ignore these terms when calculating the difference in path lengths.

$$\Delta s = 2d\left(\frac{1}{\sqrt{1-\frac{l^2}{r_0^2}}} - \frac{1}{\sqrt{1-\frac{l^2}{r_1^2}}}\right)$$

Results

- Input Parameters: $\gamma = 2000$ Lorentz factor of the base electron, $\delta = 5\%$ Energy difference, $B = 1\text{T}$ Magnetic field strength, $l = 2\ cm$ Magnet length, $d = 2\ cm$ Distance between the magnets.
- First, we used MATLAB to model a simple experiment involving 2 electrons. This was based on our theoretical calculations.
- Second, we used GPT to model a more complex experiment involving a beam of electrons.
- We examined the path length difference between the high and low energy electrons.

MATLAB	0.108326 µm
GPT	0.108297 µm
Difference	0.03%

Implications and Future Research

- We have been able to model electrons traversing a chicane.
- Due to the small difference between our two approaches, we believe our results are accurate.
- Our next step is to use the models we developed to find an optimal setup for compressing the electron bunch. This will allow us to create better quality X-rays.

Acknowledgments: We would like to thank University of Nebraska-Lincoln for funding our project through UCARE.

Reference for theoretical calculations:

Byrd, John. "Bunch Compressors." June 2010. PowerPoint Presentation.

Mamtimin, Mayir. "Design of a Bunch Compressor." PowerPoint Presentation.

University of Nebraska Lincoln