

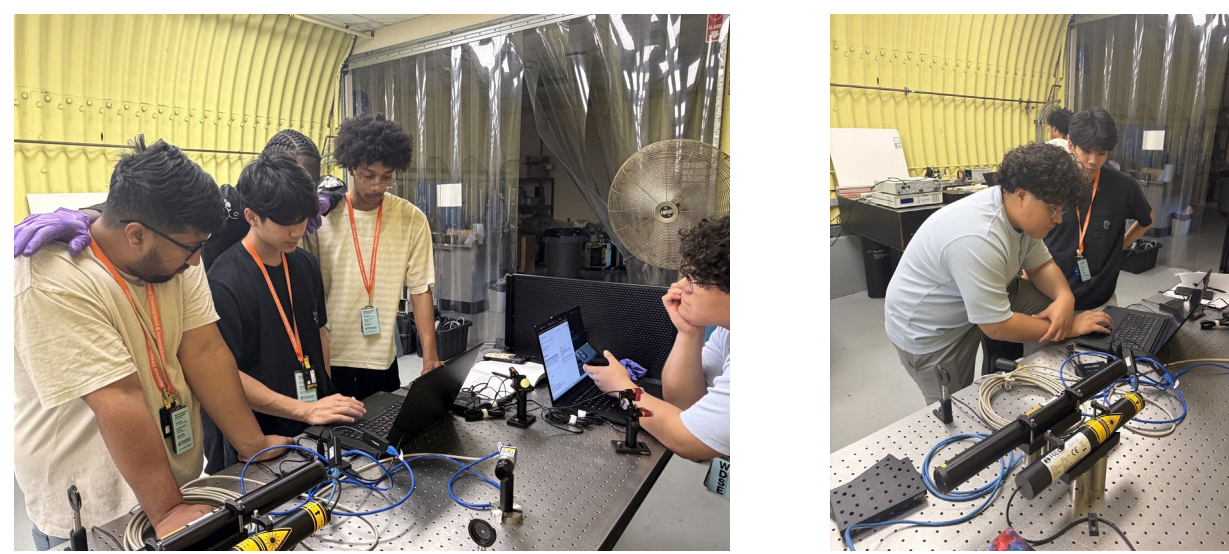
Abstract

This work presents research experience focused on accelerator operations and foundational studies in accelerator physics. The primary operational contribution consisted of implementing an automated laser alignment system to improve efficiency and assist diagnostic operations at the Accelerator Test Facility. To build practical familiarity with core accelerator concepts, additional exploratory projects were undertaken in magnetic design and beam dynamics. This included designing and simulating a quadrupole magnet to understand electron beam focusing mechanisms, as well as utilizing ImpactX to model and evaluate electron beam behavior under varying test parameters. Together, these experiences bridge hands-on facility instrumentation with theoretical beamline modeling.

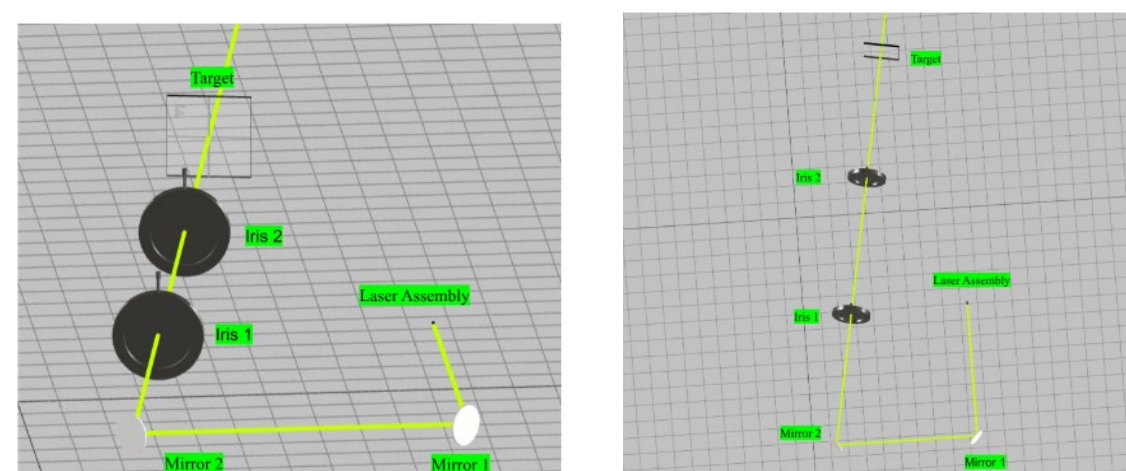
Motivation & Methodology

Automated Laser Alignment System

A primary research goal at the Accelerator Test Facility (ATF) is to accelerate particles using laser beams. To support facility operations, we implemented an automated laser alignment system to reduce component setup time and streamline mirror alignment.



- The hardware is paired sequentially. The first camera and mirror motor control the beam's alignment through the first iris, while the second camera and mirror motor guide it through the second iris.

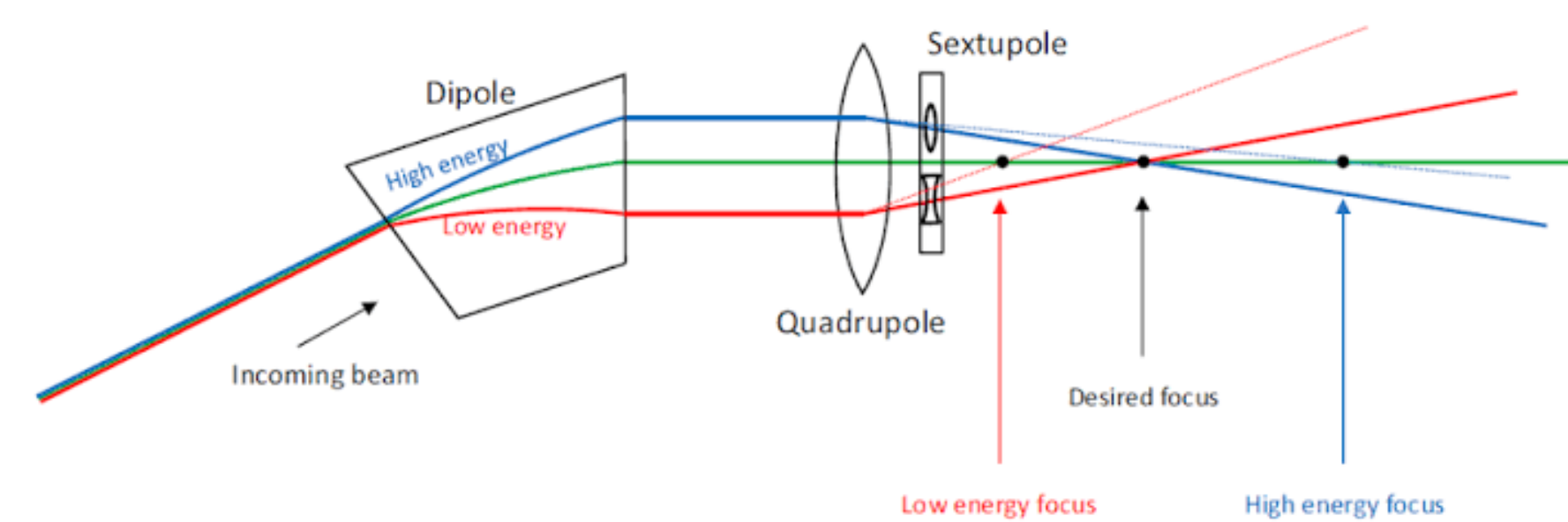


- A Basler acA1920-50gm camera calculates the beam offset at the iris, and New Focus Picomotor automatically adjust the steering mirrors.

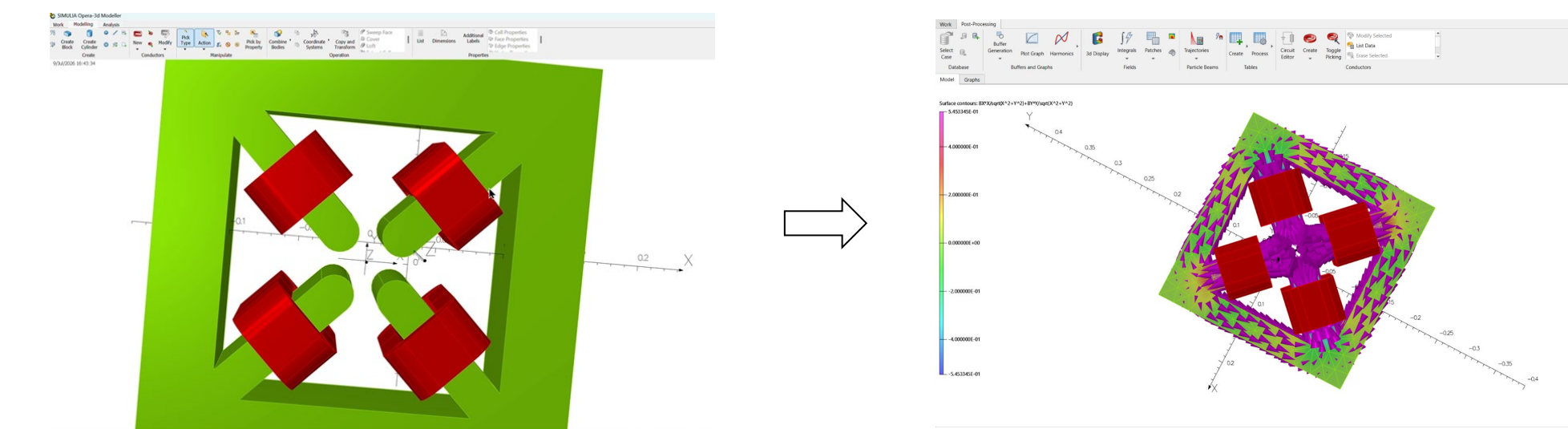


Quadrupole Design and Simulation Via Opera

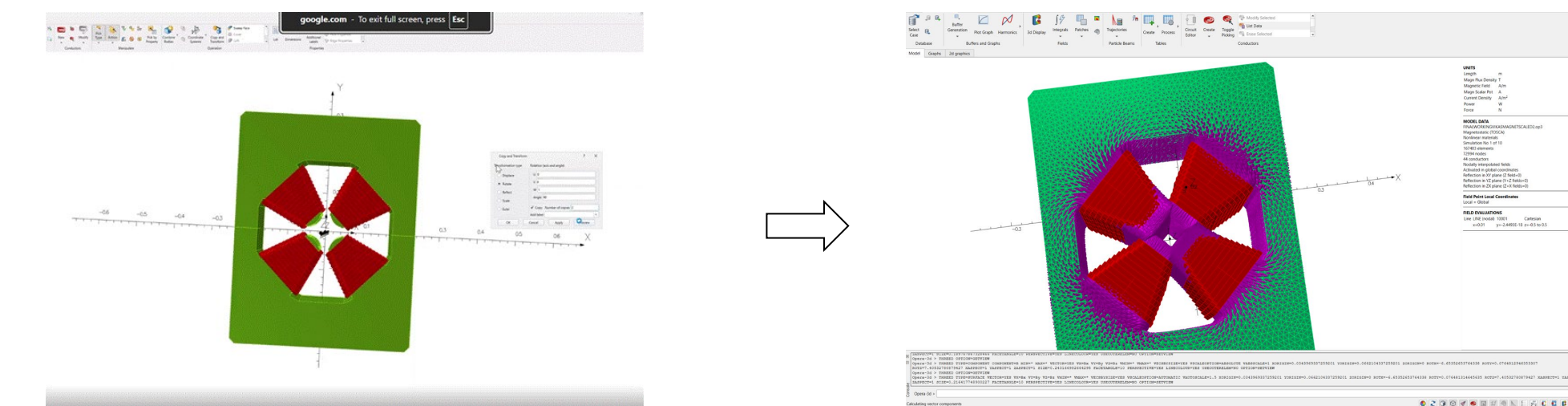
Electromagnets are crucial in accelerator science, serving as the primary tools used to steer and focus particle beams. To build practical familiarity with the fundamental physics behind these systems, we designed and simulated two quadrupole magnets using Simulia Opera and MATLAB.



- First Quadrupole Magnet (Yoke Radius=18.7 mm, length=100mm)



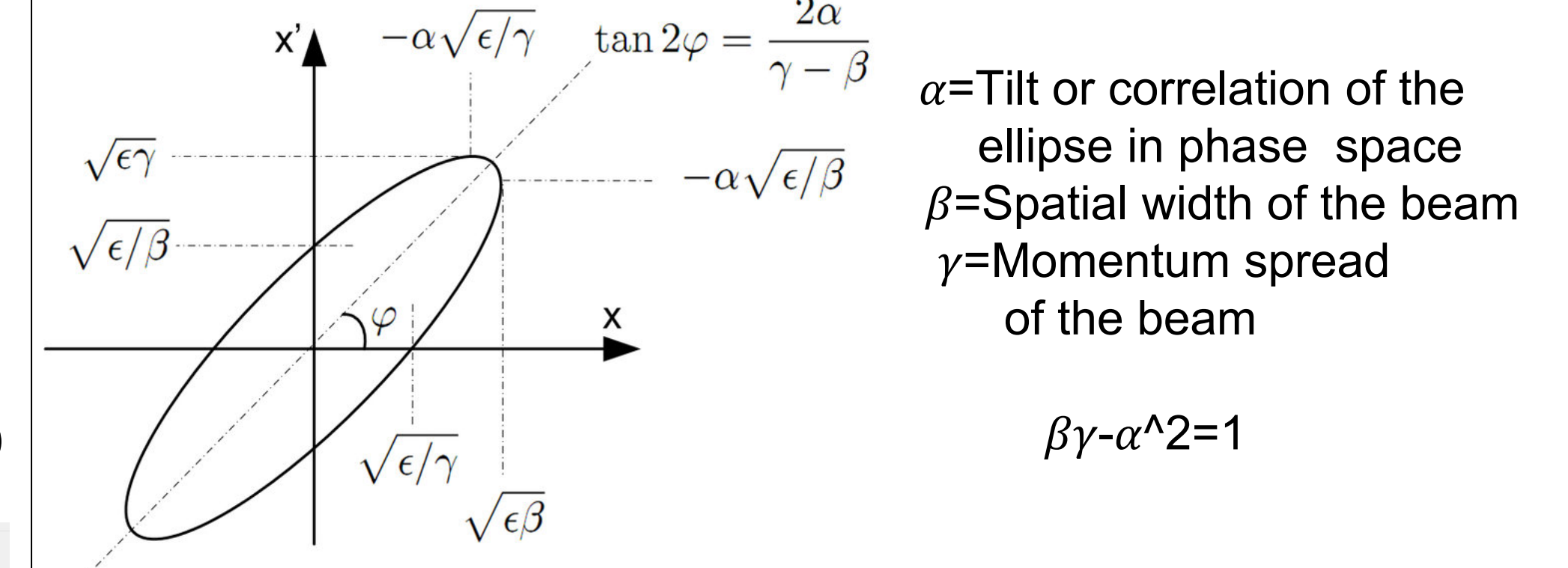
- Second Quadrupole Magnet (7552A/pole)



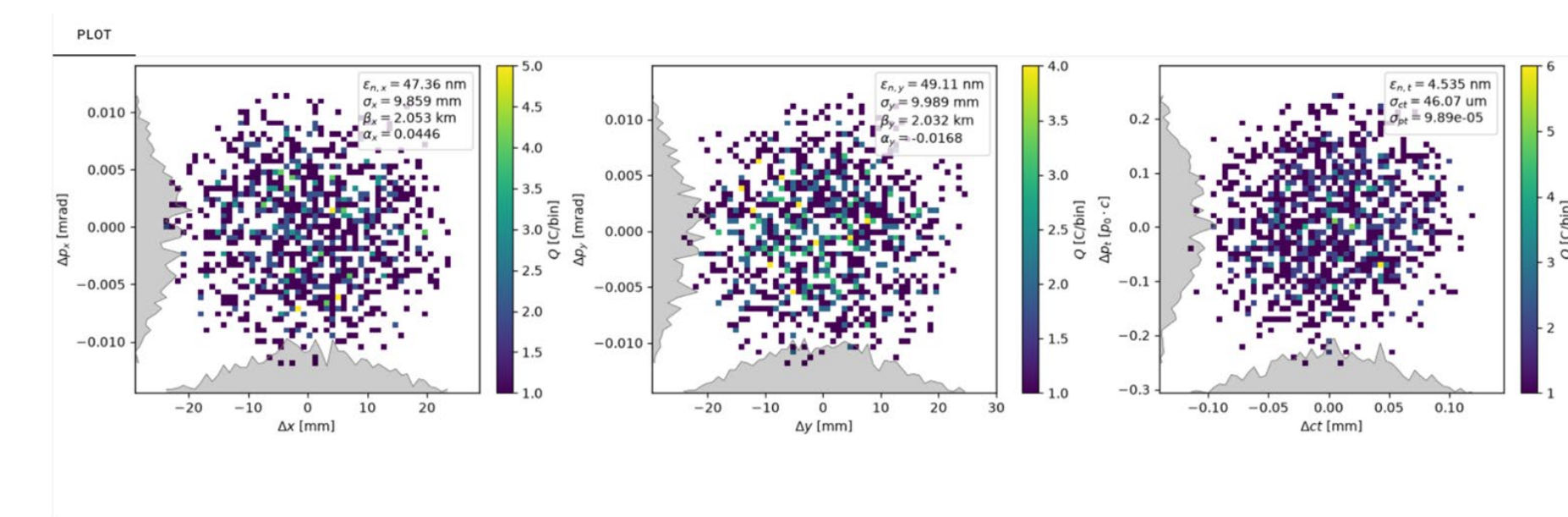
Electron Beam Simulation Via ImpactX

Ultrafast Electron Diffraction (UED) is an advanced imaging technique used to observe real-time structural changes in materials and molecules at the atomic scale. By modeling the beam profile using tools like ImpactX and testing it under different physical parameters, researchers can optimize beam transport and ensure the stability required for advanced applications like UED.

- Phase Space Ellipse of the Particle Beam



- Phase space ellipse plots the position of particles (x) against their momentum (x'), with its area representing the beam's overall quality, known as emittance (ε). We need this visual tool because the orientation and shape of the ellipse tell us exactly how the beam is behaving whether it is converging, diverging, or stable. This allows researchers to accurately design and tune focusing magnets to safely transport the electron beam to its target.

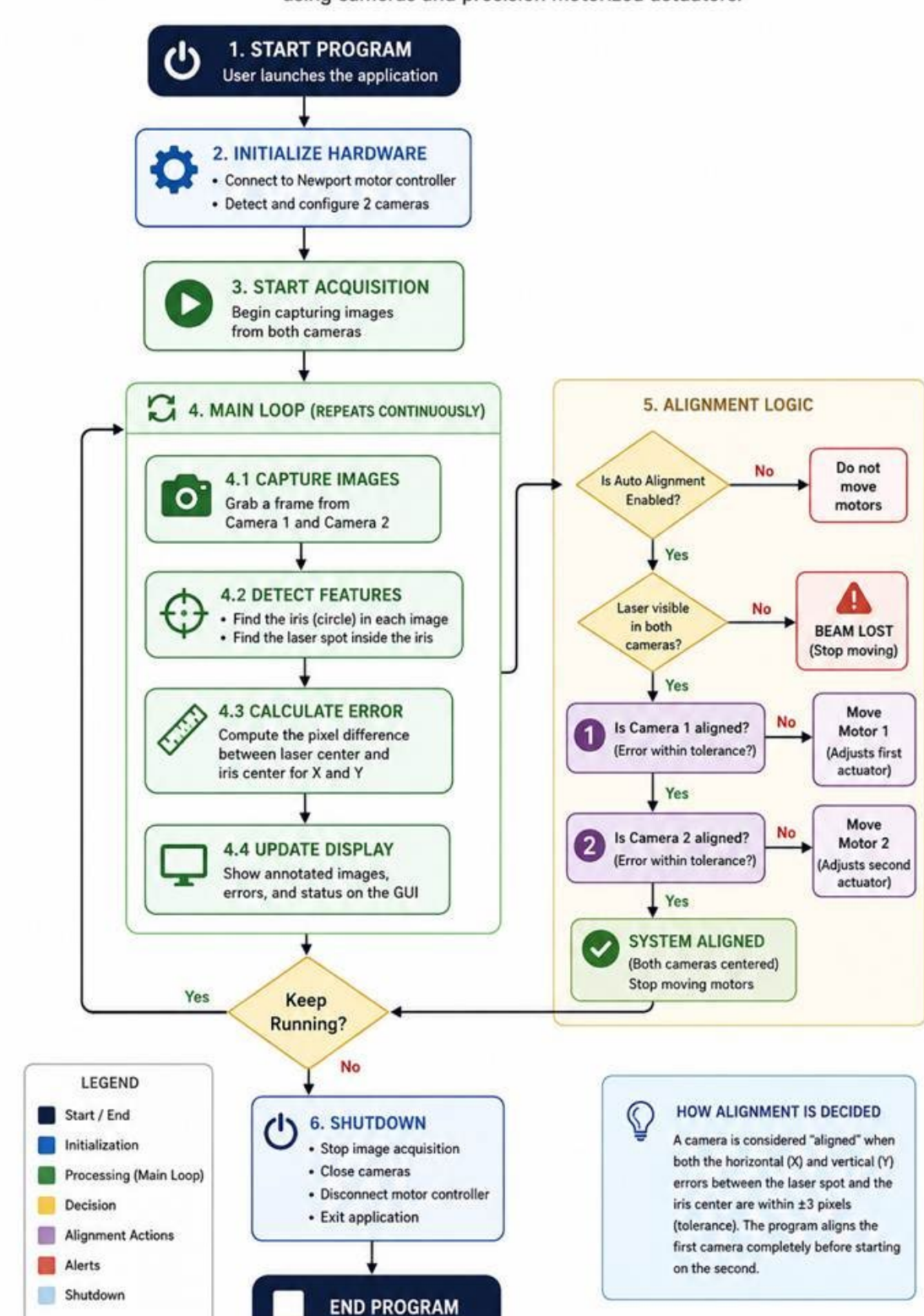


Results & Analysis

Automated Laser Alignment System

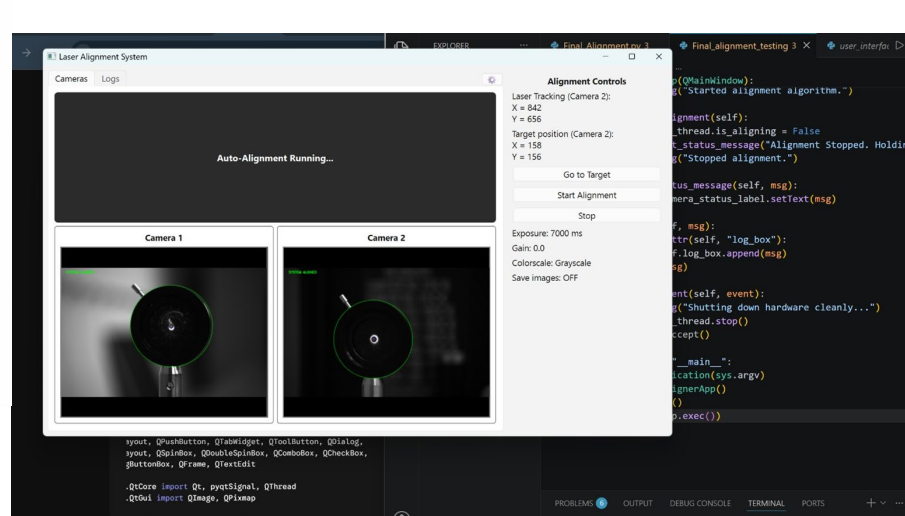
LASER ALIGNMENT PROGRAM – HOW IT WORKS

The program automatically aligns a laser to the center of two circular iris targets using cameras and precision motorized actuators.



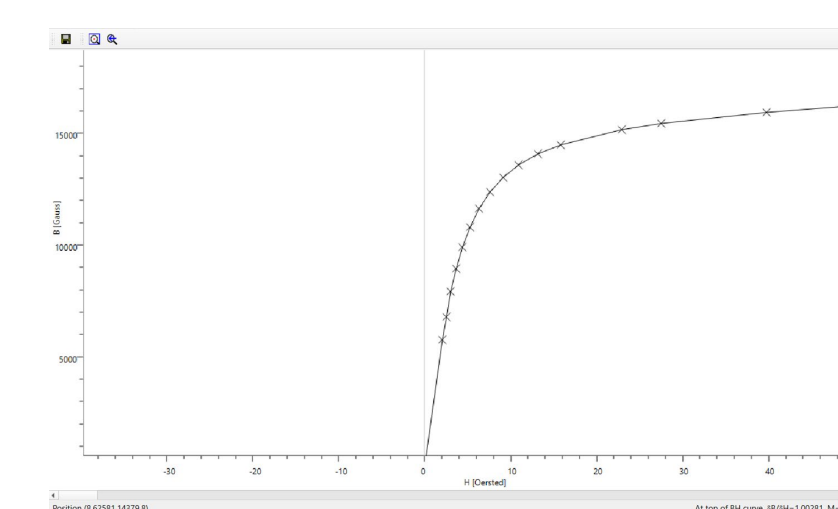
This sequential automated setup replaces a highly iterative, time-consuming manual process to rapidly achieve perfect alignment.

A user interface was developed to visualize the system's status in real-time. The program automatically switches between the two motorized cameras pairs, iteratively minimizing the alignment error until the target pixel values are reached.



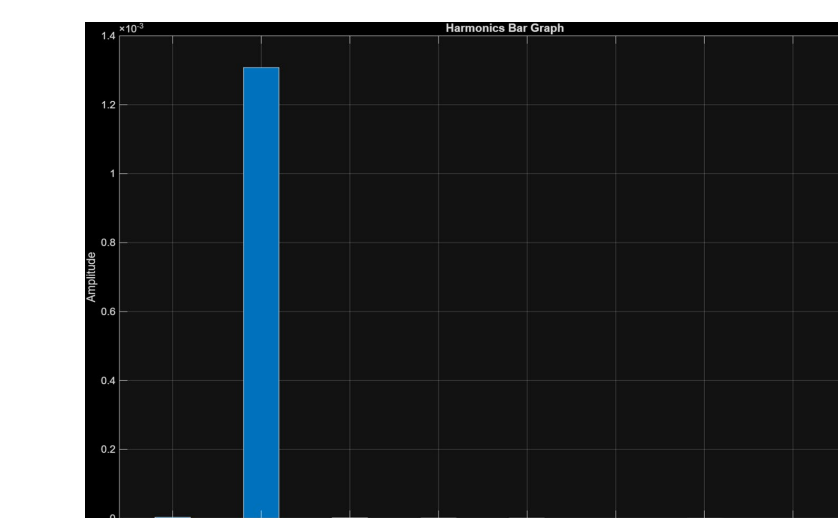
Quadrupole Design and Simulation Via Opera

- A BH curve illustrates the relationship between the applied magnetic field strength and magnetic flux density.

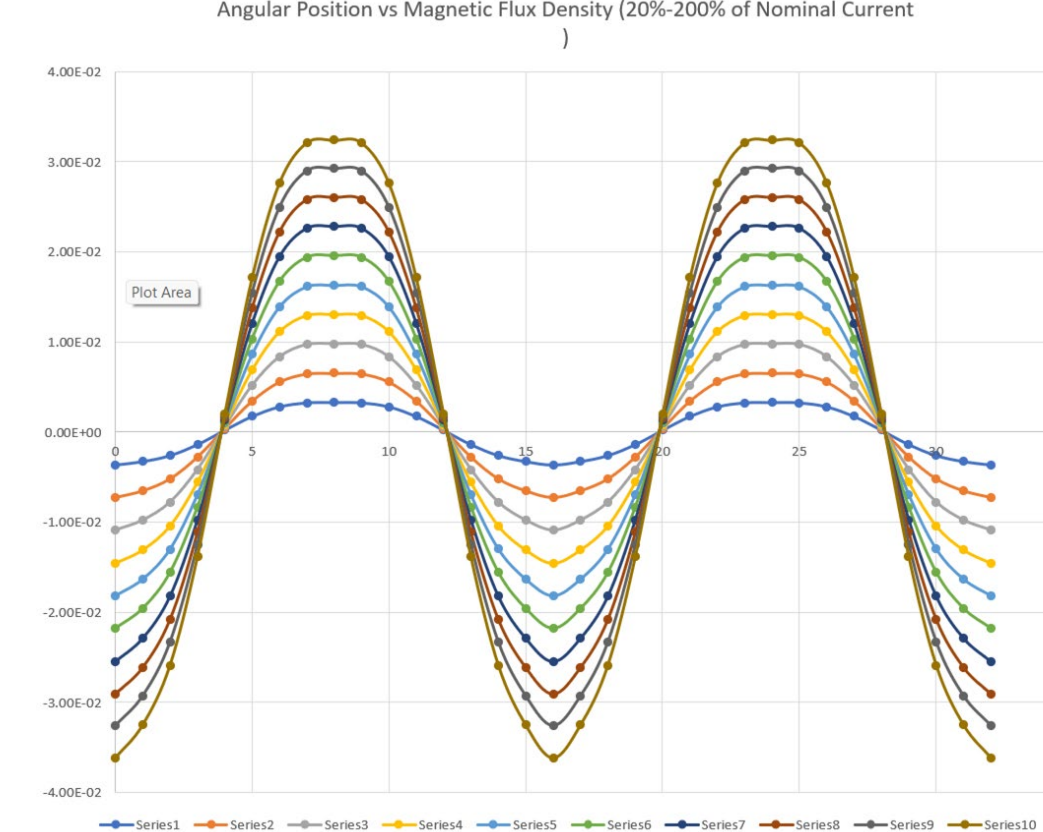


- This curve is essential in magnet design and simulation because it dictates the physical limits of the iron yoke

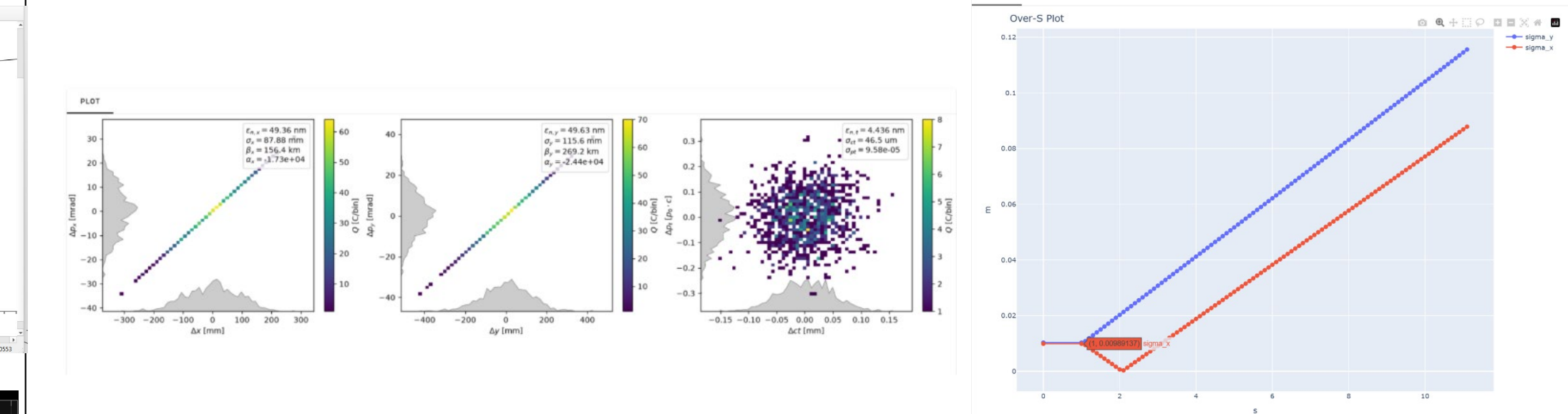
- FFT analysis helped dominant field components and unwanted harmonics.
- This allow us to detect magnet's noise and improve precision of the magnet design.



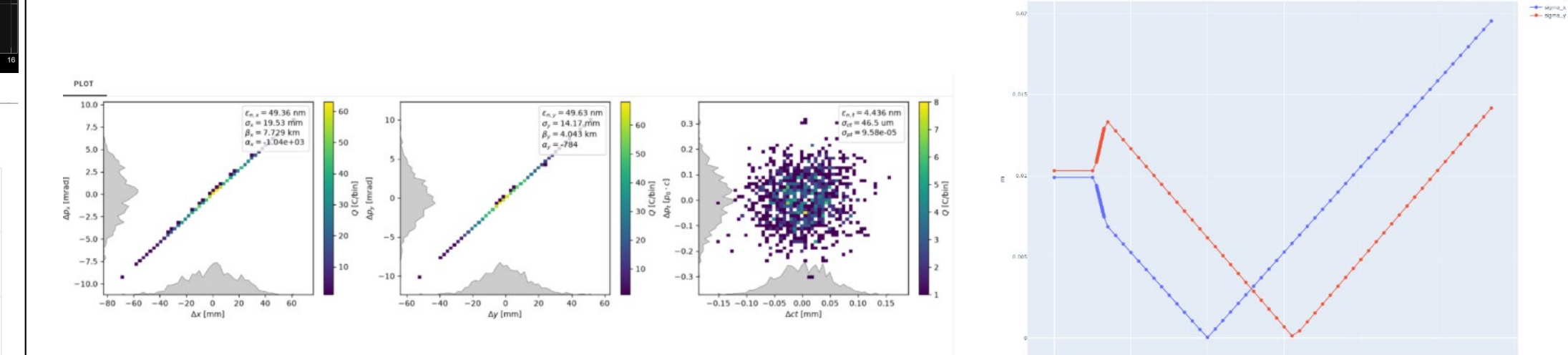
- To assess the quality of the magnetic field, we compared different radial magnetic flux density across different current densities.



Electron Beam Simulation Via ImpactX



- A quadrupole magnet focuses the electron beam along one axis while actively defocusing it along the other. In this simulation, the beam is focused in the x-axis and defocused in the y-axis.



- To focus the beam in two axis, two quadrupoles should be used; while both axes do eventually focus, they do not focus to the same point. Because the first quadrupole focuses the y-axis while strongly defocusing the x-axis, the beam's horizontal and vertical dimensions are vastly different by the time it enters the second magnet.

Conclusion

Overall, this research provided a foundational understanding of accelerator science through hands-on instrumentation and computational modeling. The work spanned three core modules: exploring the design and principles of quadrupole magnets, analyzing particle acceleration and phase space beam profiles for UED, and building an automated alignment system to support cutting-edge LWFA technology. By successfully combining software, hardware, and physical simulations, these projects delivered invaluable practical knowledge in accelerator facility operations.

Reference

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