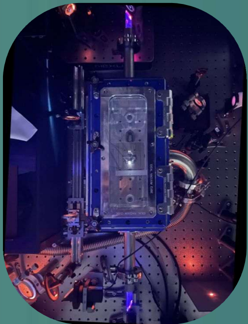
Development of an automated UV Spatial Filter for the LCLS-I photo-injector



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~ SLAC National Accelerator Laboratory ~ Stanford University ~ San Jose State University ~ Spartan Spark Internship Program Summer 2026 ~

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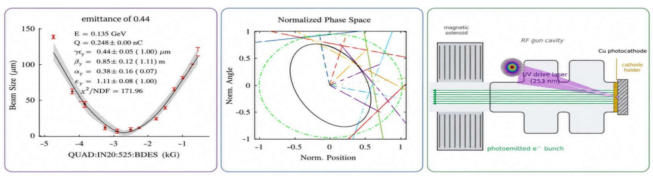
Introduction

- The Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory is one of the world's most powerful X-ray free electron lasers (XFELs). The quality of the electron beam driving this machine depends critically on the UV laser beam used to generate the electrons at the photocathode.
- The UV drive laser must have a highly uniform, clean spatial profile to produce a high-quality electron bunch
- Unwanted spatial noise and diffraction artifacts in the beam can degrade electron beam emittance, reducing FEL performance.
- This project focuses on the assembly and installation of a vacuum-chambered spatial filter to be integrated into one of the LCLS-I drive laser: **coherent 2**.

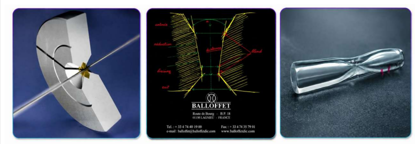
Spatial Filter

- A spatial filter — a focusing lens, precision pinhole, and collimating lens — removes high spatial-frequency noise from the beam profile by blocking it at the Fourier plane.
- This setup achieves a focused spot of ~60 microns and a suspiciously clean output profile at ACR.
- A key engineering goal is optimizing energy throughput — targeting >75% pinhole transmission — without sacrificing far-field beam quality, to deliver over 20 μJ to the cathode.
- Smaller prototype tested during MD time, improved emittance and FEL performance by **>20%.**

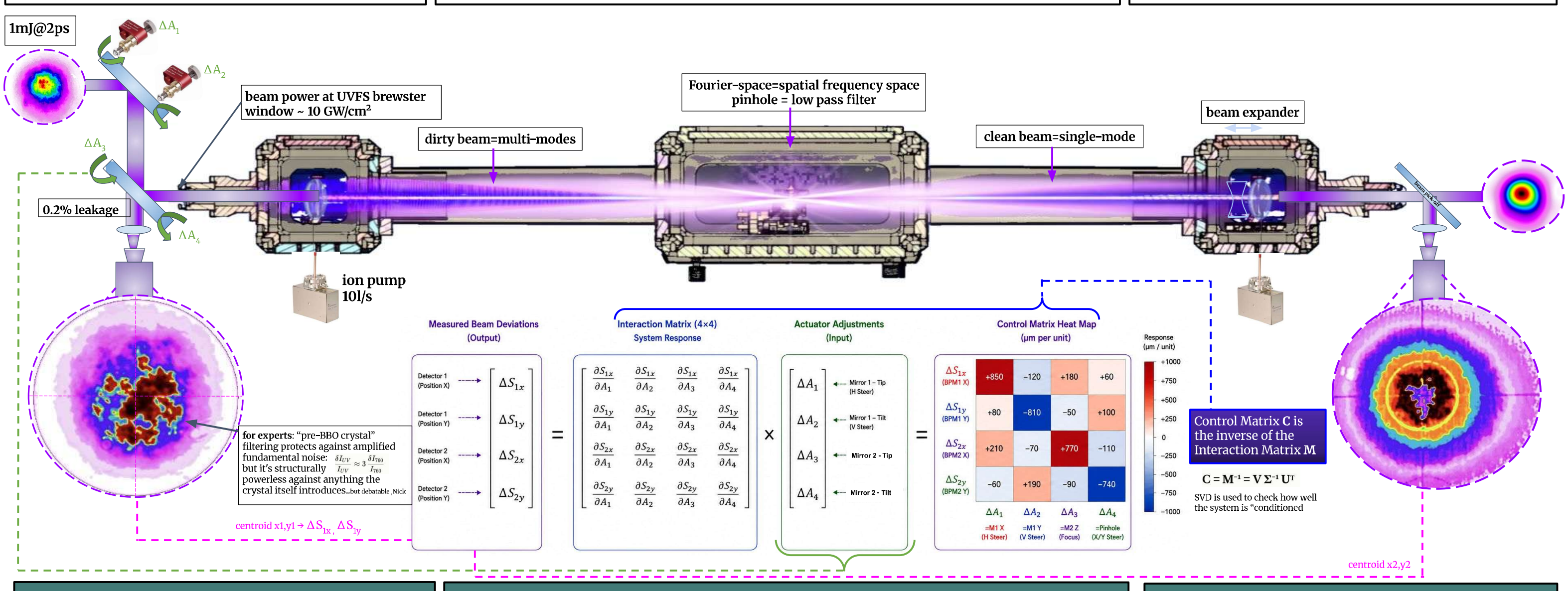


Vacuum Chamber

- Chamber preparation performed at the on-site vacuum shop at SLAC, including:
  1. Chemical cleaning of all components to meet vacuum cleanliness standards
  2. Bake-out removes contaminants that would otherwise photo-react on the optics under UV illumination.
  3. 2x10l/s Ion pumps ordered to avoid vibrations

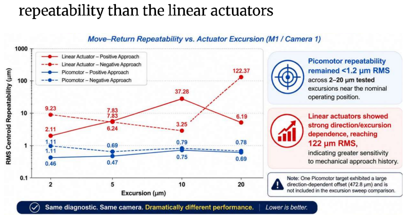


diamond pinhole – polycrystalline dye glass capillary



Motor Analysis Study

- Comparing linear actuators vs. picomotors on the test bench was important to validate our design choice of picomotors for the spatial filter controls
- Picomotors proved to have less backlash and higher repeatability than the linear actuators



Controls Development via EPICS

- The laser test bench which contains a 2 mirror, 2 camera setup was utilized to learn the fundamentals of controls scripts and beam centering via python and EPICS
- The test bench was also modified and utilized to run the motor analysis study
- The beam centering feedback loop operates by using a 4x4 interaction matrix (Jacobian) and its inverse, the control matrix, to align itself using picomotors

Motorized actuator TRA25CC "step size" : 200nm | Picomotor piezo linear actuator 8302, step size: < 30nm | GigE camera | Pinhole

Results and Conclusion

- Assembled and prepared the vacuum chamber for integration into the LCLS-I photo-injector.
- Development of the interaction-matrix control framework established the foundation for automated beam steering using EPICS and Python.
- The optical, mechanical, and controls studies validated the overall system architecture and reduced technical risk prior to installation at the photo-injector.

Future Work

- Complete installation and alignment on coherent 2.
- Continue the integration of EPICS-based controls with the full optical system.
- Continue commissioning the system for routine LCLS-I injector operation

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