Right on Time: Modeling the LCLS-II Arrival Time Monitor to Quantify Edge Detection Error

Logan Curley[1,2], Mike Glownia[1], Pamela Bowlan[1], Mathew Britton[1]

1. SLAC National Accelerator Laboratory 2. University of Arizona

References and the Simulation

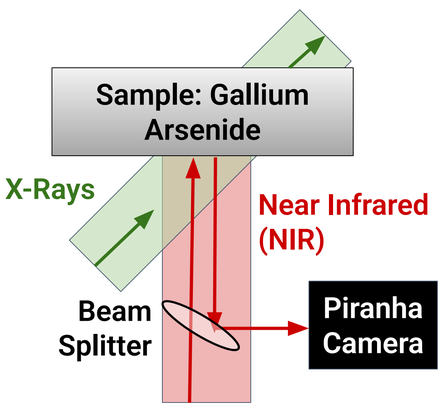
Scan Me!

ATM Background

Faster than electronics, **pump-probe spectroscopy** at LCLS uses two lasers to image ultrafast dynamics:

Pump Laser: Generates a change in state
Probe Laser: Measures that change

Precise laser timing is critical, but shot-to-shot "**jitter**" arises since x-rays generate far from the hutches



Arrival Time Monitor (ATM):

Measures timing delay between the two lasers for each shot

Temporal data encoded in space

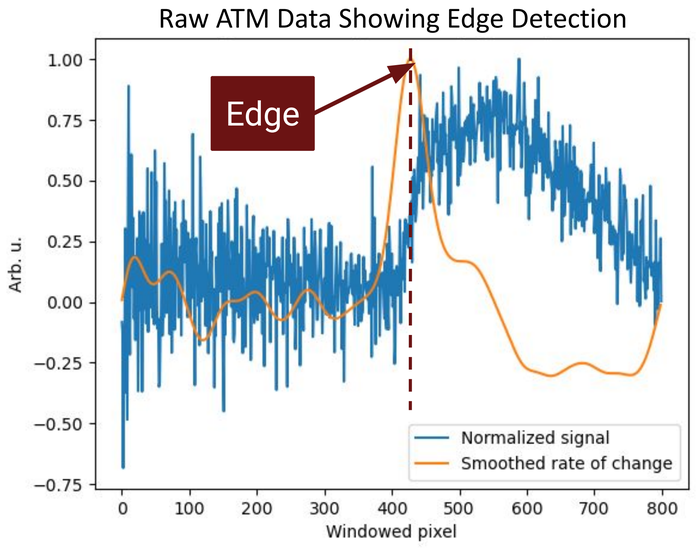
1. Sample Pumped by X-Rays
2. Sample Changes Reflectivity
3. More Infrared Reflects Back
4. Signals X-Ray has Reached Target

Periodically collect unpumped **background signal,** important in data analysis

ATM for the LCLS-II

LCLS (the x-ray laser) recently upgraded from 120 Hz to 71 kHz, making it necessary to **remodel** the ATM

Raw ATM Data Showing Edge Detection



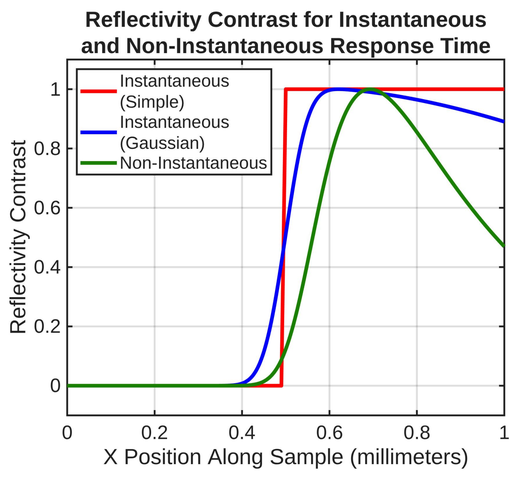
Modeling enables error **quantification** in edge detection

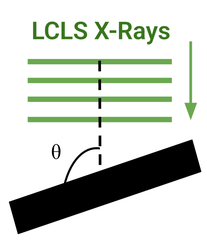
Simulation initially created in MATLAB software with an interface for the user

Interface removed and converted to Python using Claude to better analyze error

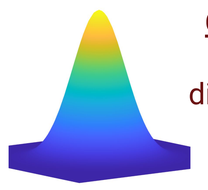
Simulating the ATM

Material Response:





Simple: Angle causes space to map to time

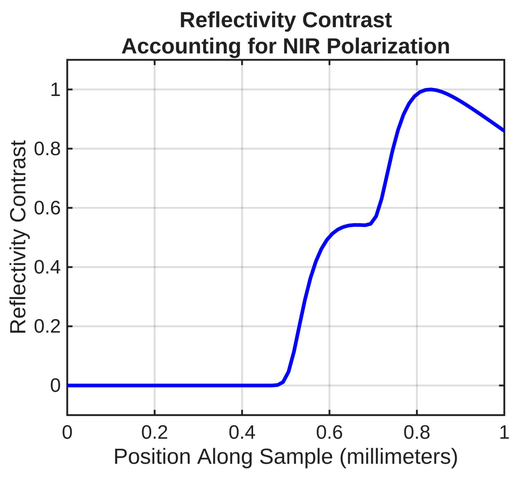


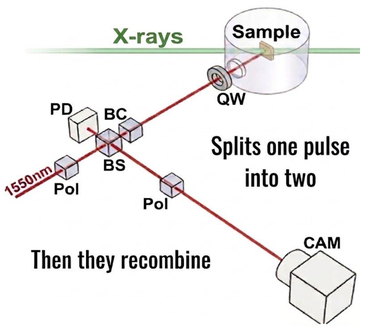
Gaussian: Intensity distributions are **not** uniform

Non-Instantaneous: Material does not change instantly.

Delay to start changing, delay to stop, and decay back to original

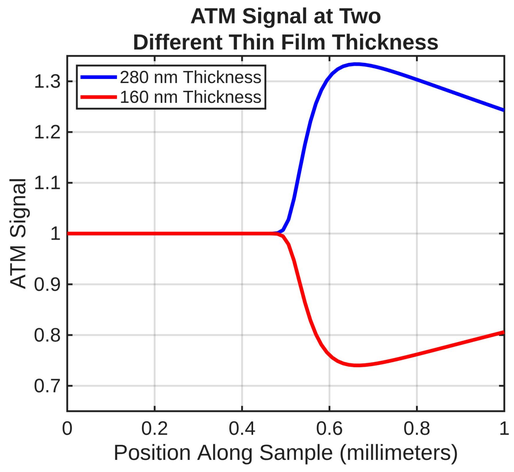
Infrared Polarization:

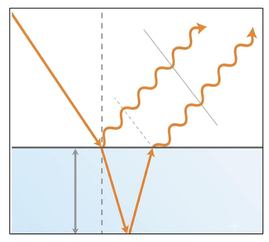




Infrared beam passes through polarization elements to isolate the signal **interferometrically**

Thin Film Interference:

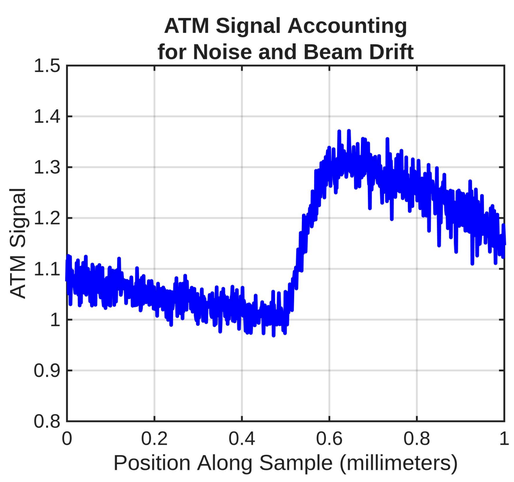


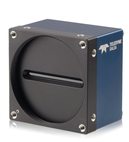


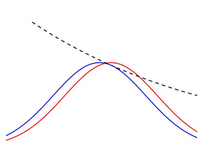
Light reflects off top and bottom of a thin film

Reflections interfere to **reduce** the background

Noise and Laser Drift:







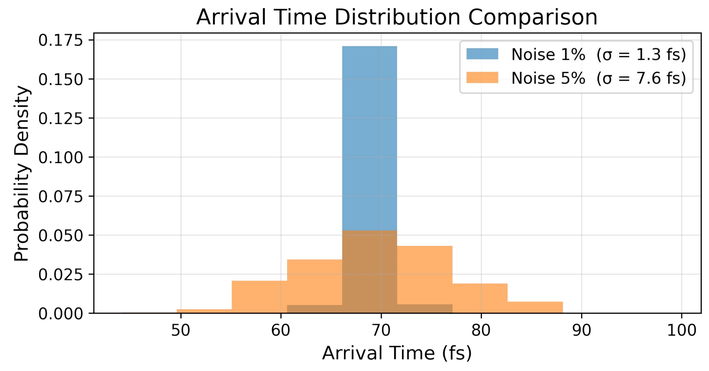
Noise: Unwanted, electric static from Piranha4

Drift: Beam deviation modeled as a **slope**

Error and Edge Detection

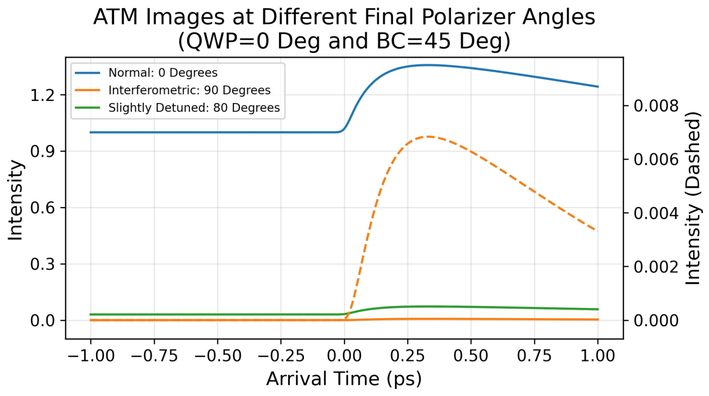
Analysis in Python gave **two** important conclusions

1. Changed each variable slightly and repeatedly calculated edge arrival time to see variation



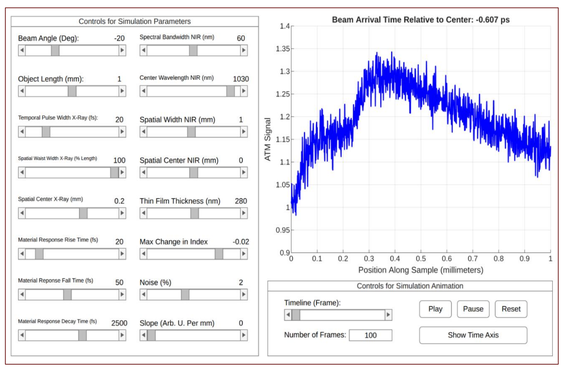
Noise is the **main** source of error and can be made worse by other parameters smoothing the signal

2. Polarization elements can increase the signal by interferometrically canceling the background



Slightly detuned components allows for **more** light on the sensor while still isolating the signal

Conclusion and Future Steps



GUI allows users to alter **22** different parameters to visualize the ATM and gain intuition for setup **optimization**

Python simulations test edge detection algorithms against a ground truth and quantify error in **real** signals

Next steps involve adding more parameters **and** increasing complexity in existing ones

UNDER CONSTRUCTION 22→∞

Acknowledgements

I want to thank all of the SLAC staff who helped provide me with this opportunity. Specifically, thank you to Mat for choosing to mentor and work with me. And thank you to Pam for helping go over topics with me.