Characterization and Simulation of Optical Delay System for the Proof-of-Principle Experiment of Optical Stochastic Cooling at IOTA

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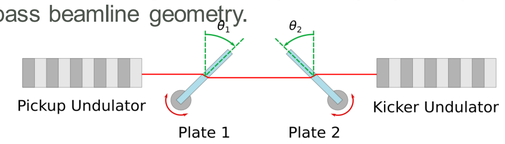
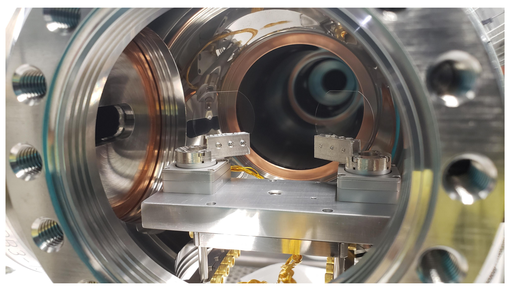
Introduction

The Optical Stochastic Cooling (OSC) experiment at Fermilab's IOTA storage ring uses two undulators to cool a 100MeV electron beam over many turns. The radiation emitted by electrons in the first undulator is delayed and imaged in the second undulator where it applies a corrective energy kick on the beam. Imperfections in the manufacturing of the delay plates can lead to a source of error. This project experimentally determines the absolute thickness of these delay plates using an interferometric technique. The measured "thickness maps" are implemented in the Synchrotron Radiation Workshop (SRW) program to assess their impact on the delayed radiation pulse. The procedure is outlined more fully in the technical note [1].

Delay System

Two 0.25-mm rotating glass plates will be inserted in the optics line so to provide a variable delay. By changing the angle of the glass plates, the optical path length experienced by the undulator radiation changes. The two plates are placed in a symmetrical configuration to minimize the transverse displacement of the photon beam as the delay (i.e. the angle of the plate) is varied. The maximum delay is limited to 0.648 mm and 2.0 mm for the for passive-OSC and active-OSC configuration respectively by the particle-bypass beamline geometry.





Haidinger Interferometer

Haidinger Interference

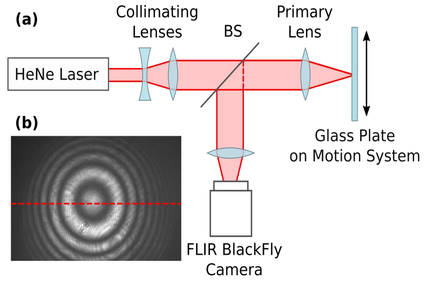
Haidinger's interference fringes refer to interference patterns in which coherent, monochromatic light incident on a thin film produces fringes at equal inclination. The interference is a result of the reflection from the front andback faces of the thin film according to:

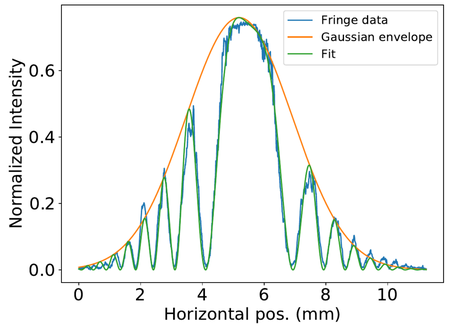
$$I(\theta) = I_0 \sin\left[2tn\cos\left(\frac{n}{n_{air}}\sin(\theta_i)\right) + \frac{\lambda}{2}\right]$$

The inteference pattern (b) is observed using a CCD camera and a line-out (shown in red) is taken along the x-plane for anaylsis.

Fitting_Data

The plate is scanned across the x-y plane over an area of 22mm x 12mm and the thickness is determined for each point producing "thickness maps" of each plate. The fit shown to the left is a combination of the interference equation multiplied by the gaussian profile of the HeNe laser beam.





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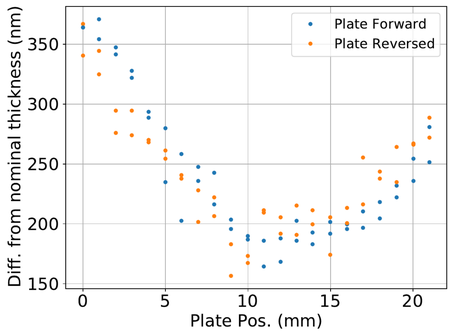
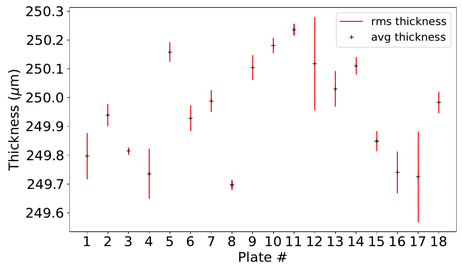
To verify this method, we attempted to reproduce the same thickness profile of the same plate when measured from oposite directions. The two scans are in good agreement which suggests this method is fairly robust and sensitve on the ~20nm level.





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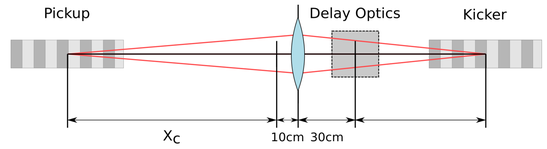
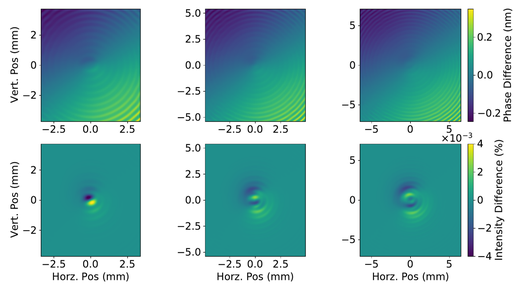
There were a total of 18 plates that were measured by this technique. The average thickness of each plate deviated from the nominal by less than 300nm and had an average rms spread of about +/- 70nm. Some plates have large total variations but are relatively flat in a single direction.

SRW Simulation



Wavefront Simulation

Synchroton Radiation Workshop is a wave-optics simulation program including simulation of synchrotron radiation from first principle. The simulation consisted of using SRW to propagate the undulator radiation through the IOTA optics line including the delay plates. We first simulated the nominal 0.25mm parallel-face delay plates and extracted the phase and intensity information at points within the kicker undulator. The simulation can be rerun with the measured thickness maps inserted for the delay plates. The effects on the phase and intensity of the undulator radiation in the kicker undulator is very small and will have almost no effect on OSC.



Acknowlegements

This work is supported by U.S. Department of Energy under award No.DE-SC0013761 with Northern Illinois University and by the U.S. NationalScience Foundation under award PHY-1549132, the Center for BrightBeams. Fermilab is managed by the Fermi Research Alliance, LLC forthe DOE under contract number DE-AC02-07CH11359

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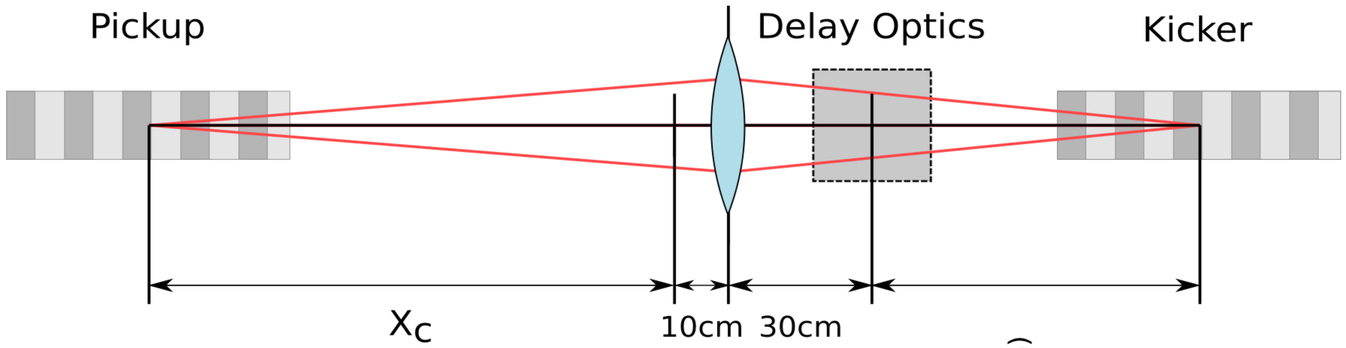

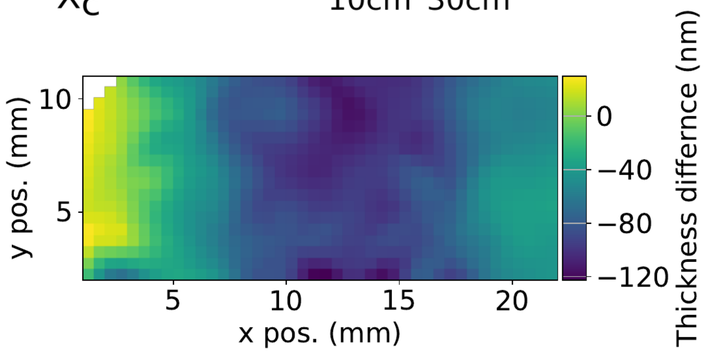

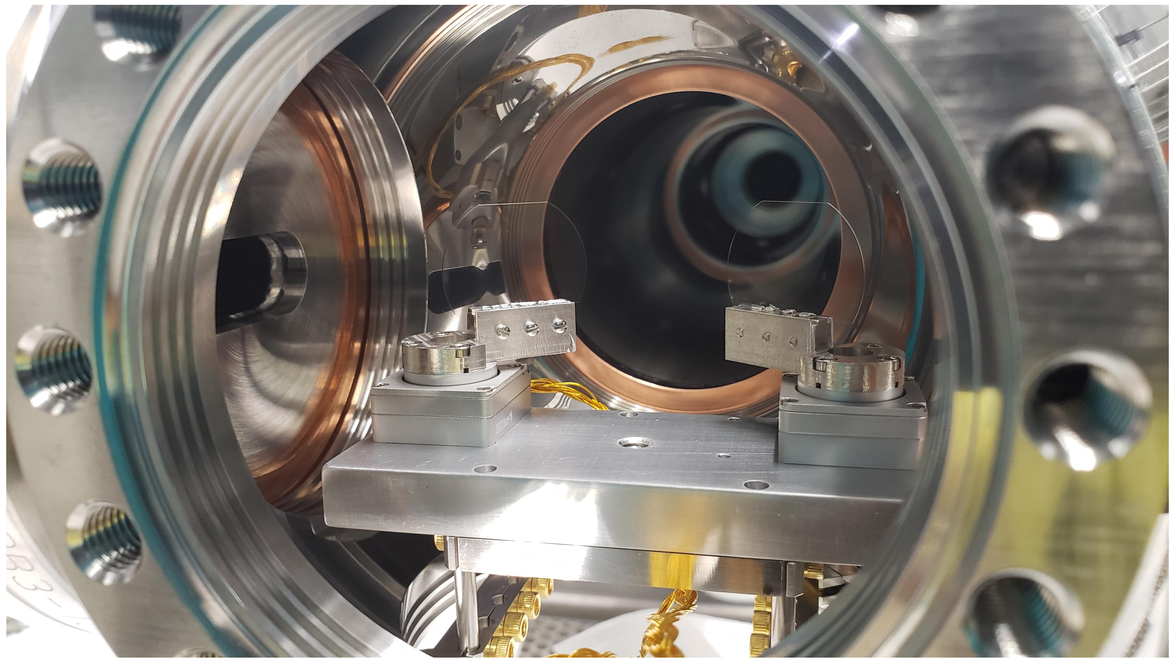

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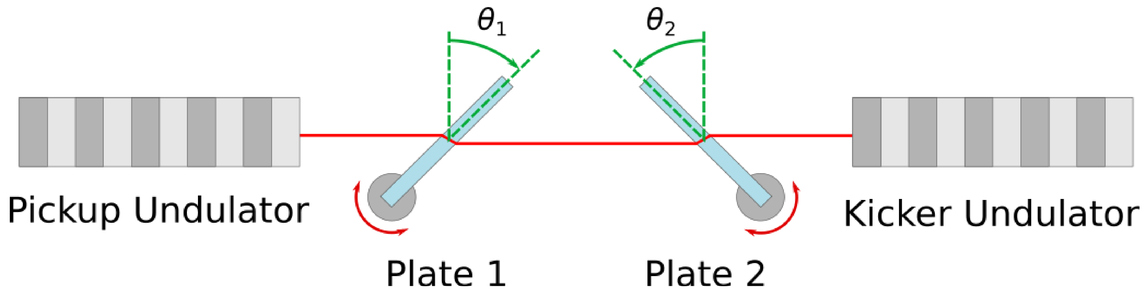

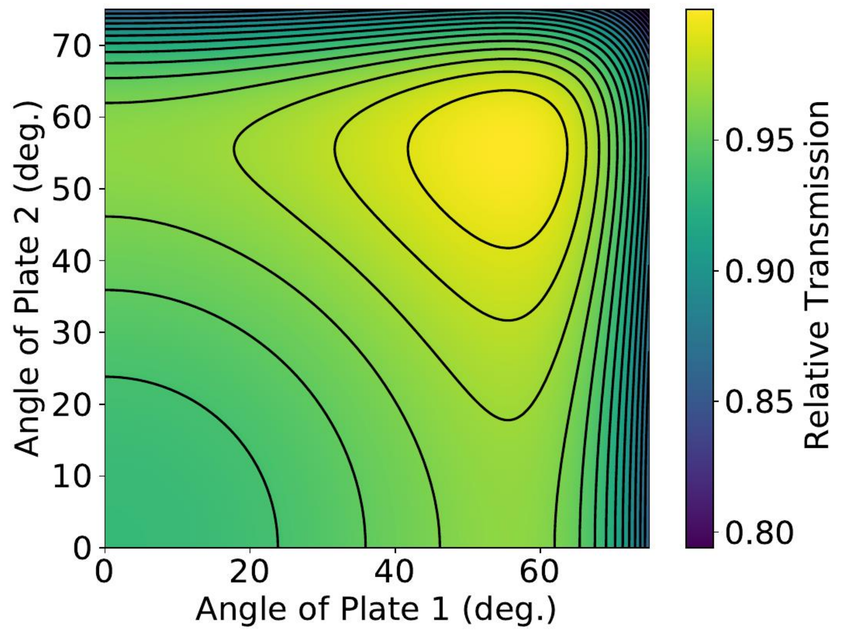

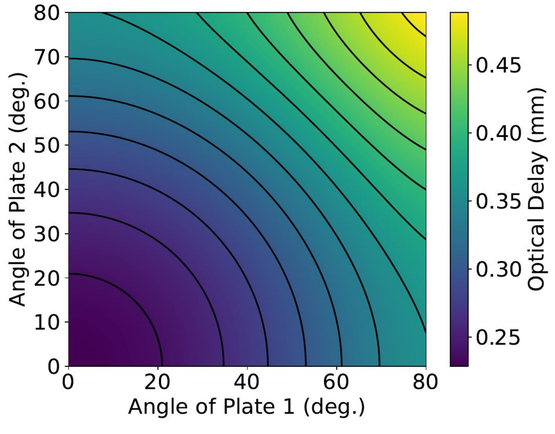

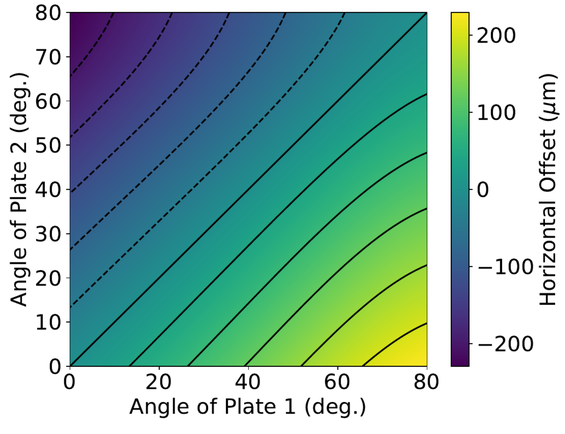

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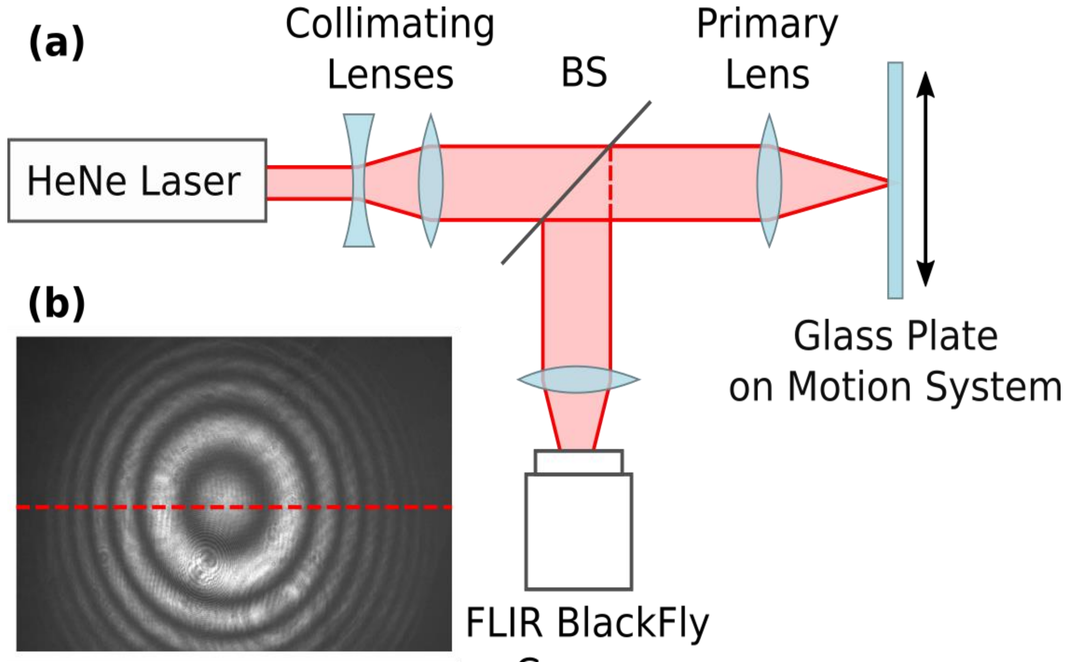

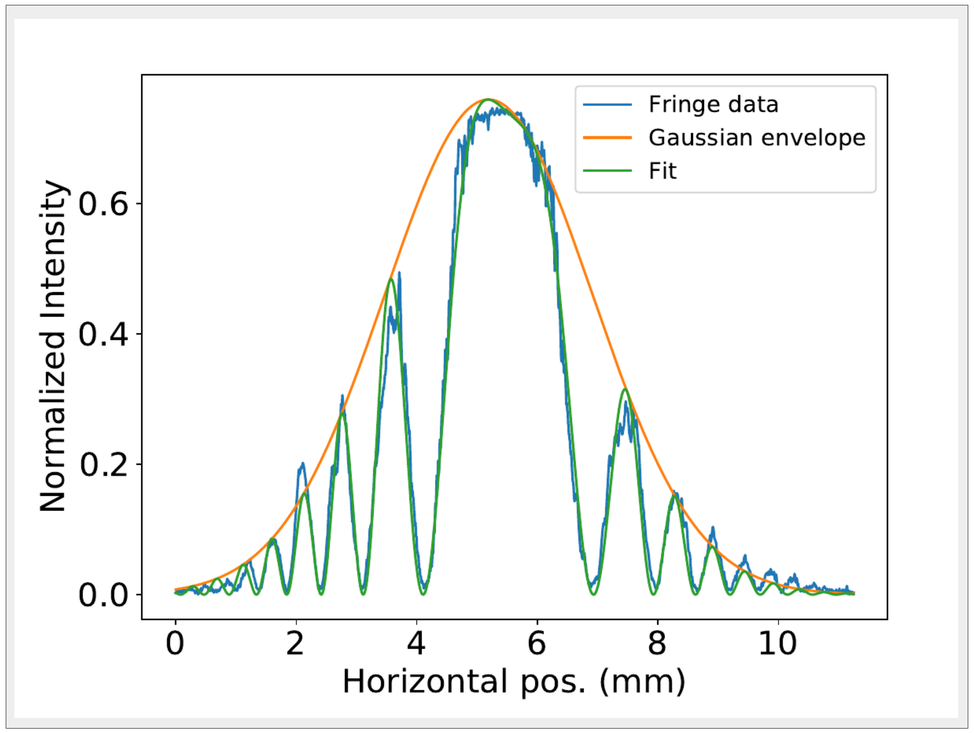

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Measurement Results

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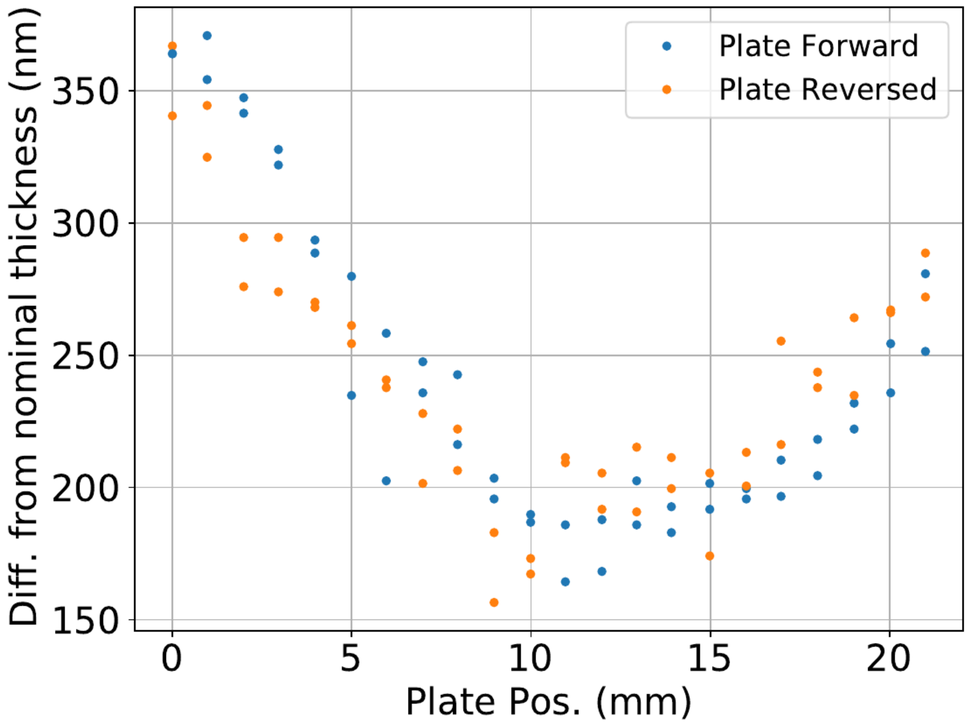

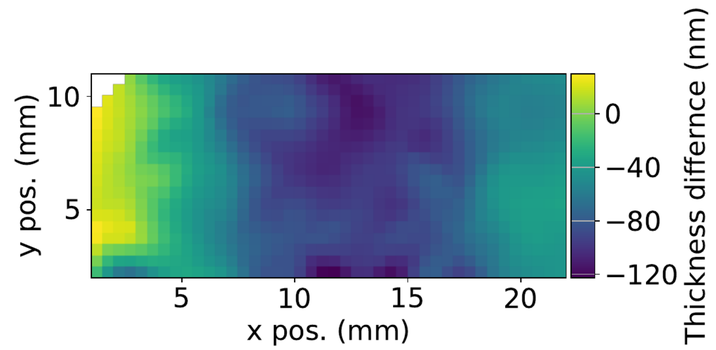

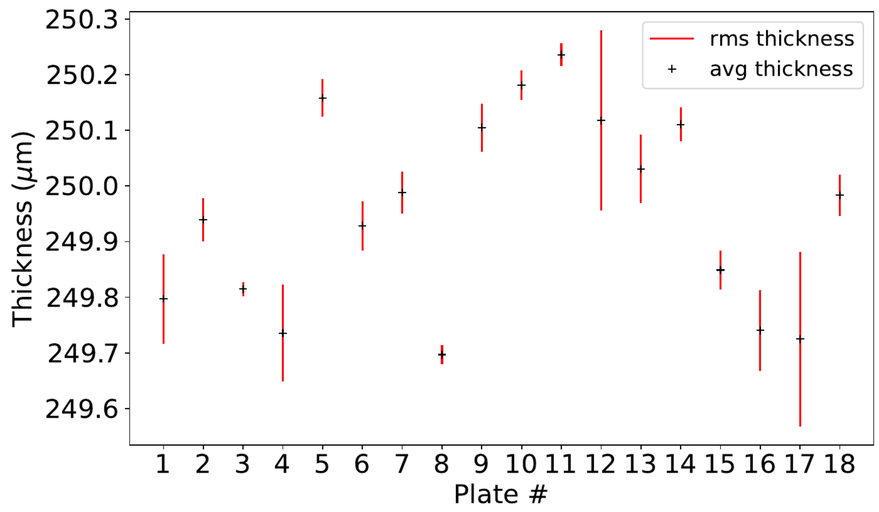

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