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Diagnostics to study electrothermal instabilities on Mykonos*

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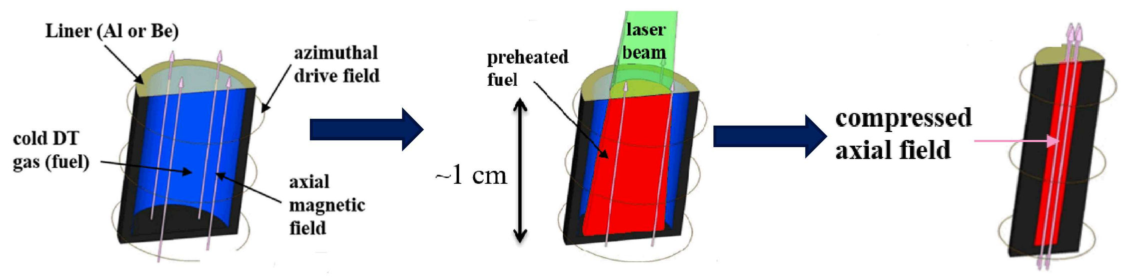
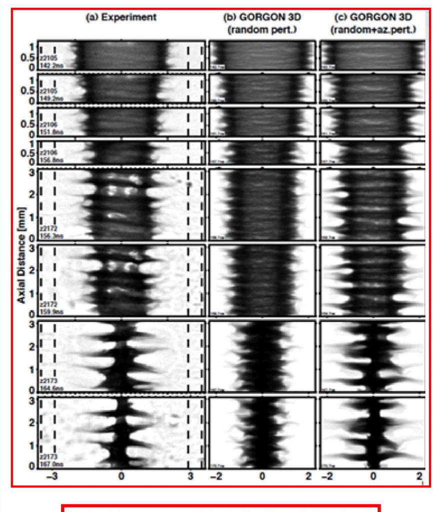
Magnetized Liner Inertial Fusion (MagLIF[1]):



S.A. Slutz *et al.*, PoP **17**, 056303 (2010)

•20 MA of current flows through beryllium liners (about 500 µm thick)
•Fuel/liner is axially magnetized, then fuel is laser heated
•Liner is accelerated to nearly 70 km/sec, compressing the premagnetized/preheated fuel
•Fusion-relevant conditions are achieved, but limited by Magneto-Rayleigh Taylor (MRT) instabilities[9]

Gomez, M. R. et al. Phys. Rev. Lett. 113, 155003 (2014)

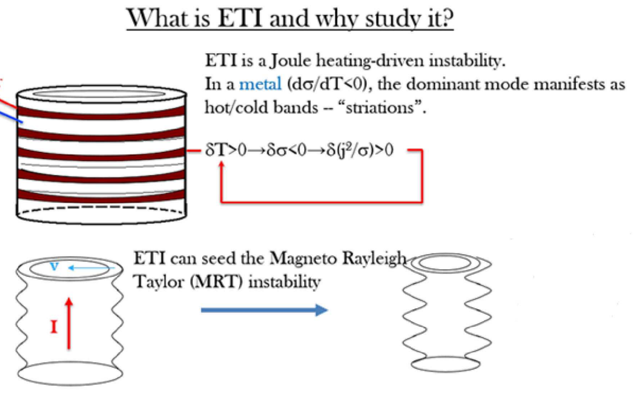


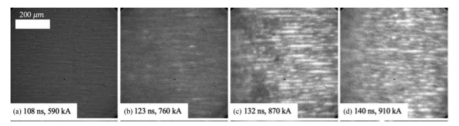
McBride *et al.*, PRL **109**, 135004 (2012)

- Simulations only match experiments when azimuthally correlated perturbations are added. These perturbations do not match experimental linear initial conditions. → Some phenomenon is generating them dynamically.
- One simulation-supported hypothesis is called the electrothermal instability (ETI), which generates azimuthally correlated temperature and density perturbations called strata/striations.

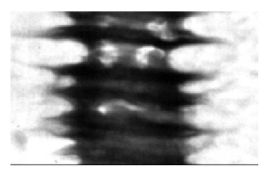
Ryutov *et al.*, Rev. Mod. Phys. **72** 167 (2000)
Orshekin *et al.*, PoP **15**, 092103 (2008)

Electrothermal instabilities (ETI) are thought to seed MRT instabilities





Discrete strata can be seen on ohmically heated, thick aluminum



MRT seen on a liner

Mykonos-V is a five stage Linear Transformer Driver (LTD) voltage adder

Machine specifications

At full-charge voltage:
•≤1 MA into 0.5 ohm load
•500 kV pulse
•Rise time (10%-90%) of 80 ns through a barbell load
•Pulse width (FWHM) of 160 ns
•LTD module made of five, three-meter diameter LTD cavities

Barbell targets with engineered defects provide insight on ETI

Observation: Low intensity emissions, a likely result from overheated inclusions in alloyed aluminum, drive ETI in Z pinch targets.
Objective: Experimentally study the evolution of ETI from targets with well-understood and well-characterized engineered defects for comparison with simulations.

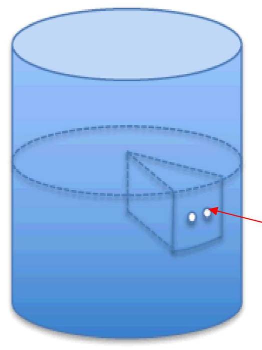
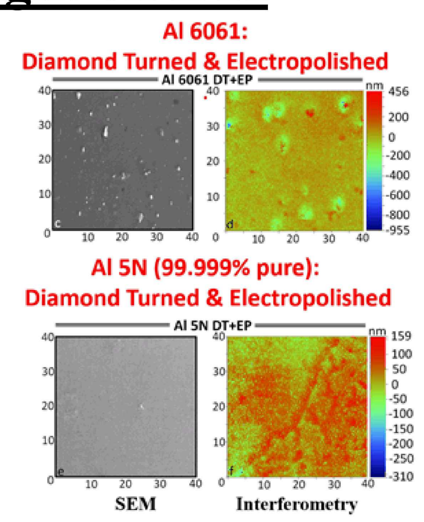


Figure a.)

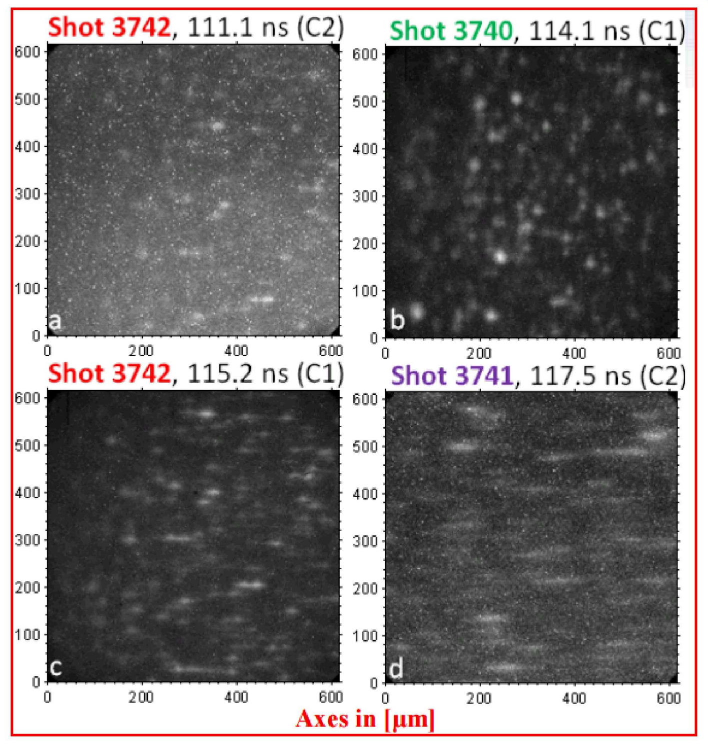
-Ultra-high purity aluminum loads are diamond-turned to near perfect finish, then defects are added

Defect is largest perturbation on the current density

-Engineered defects (informed by the study of alloys) will allow for the investigation of well-characterized perturbations that are predicted to drive ETI.



Diamond turned and electropolished aluminum targets will be used to decrease number of incidental inclusions



Non-uniform emissions are shown to evolve quickly from Al 6061 surfaces, as seen in the figure above.

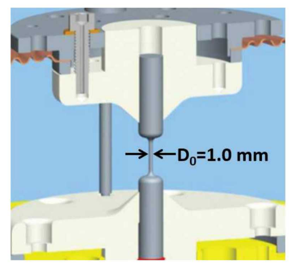


Figure b.)

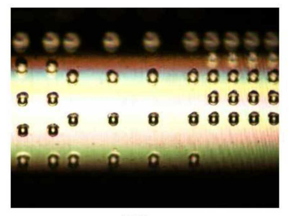


Figure c.)

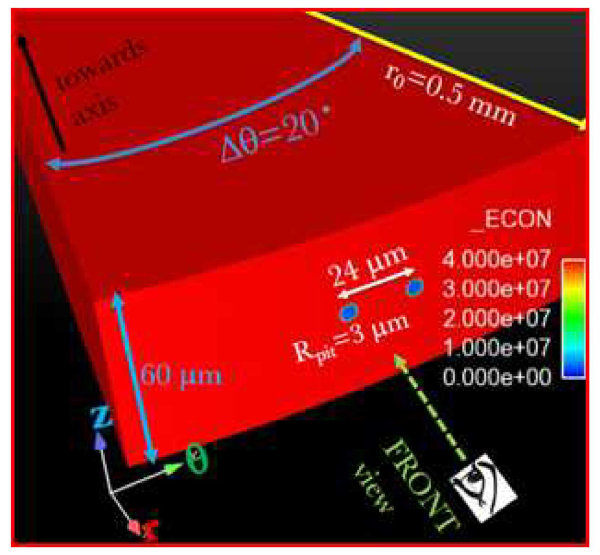
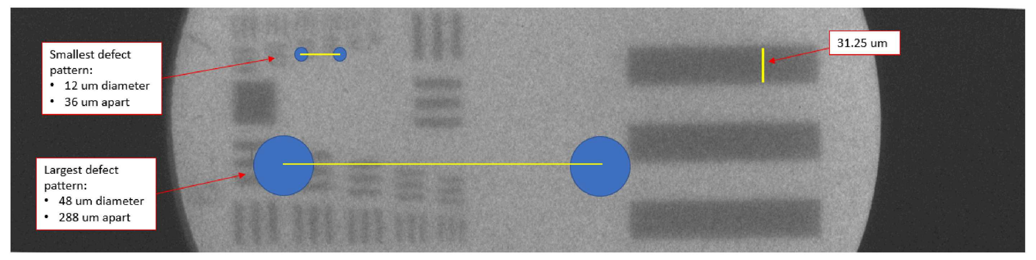


Figure d.)

Examples of engineered defects can be seen in Figure a). Figure b) shows the barbell and mount. Figure c) displays a picture of an engineered barbell with defect patterns. Figure d) displays the initial perturbation geometry for a 3D MHD simulation of barbell target with micron scale engineered defects.



Superposition of to-scale defect pattern simulations on Andor iStar 340T ICCD with USAF 1951 resolution test chart. Path length is 60 inches, $M = 31.25$.

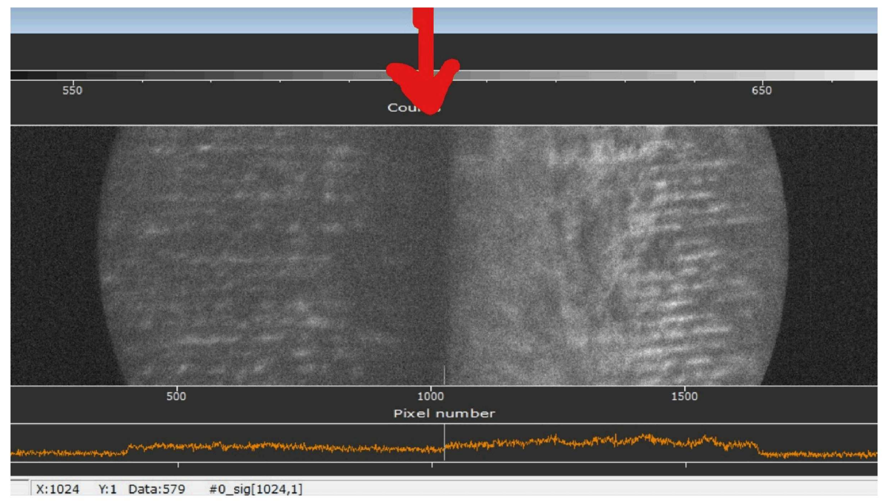


Figure a

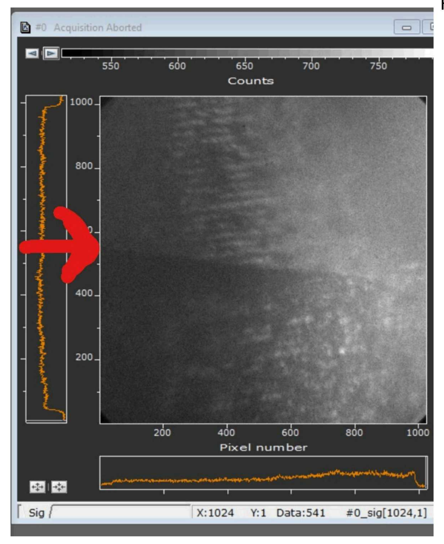


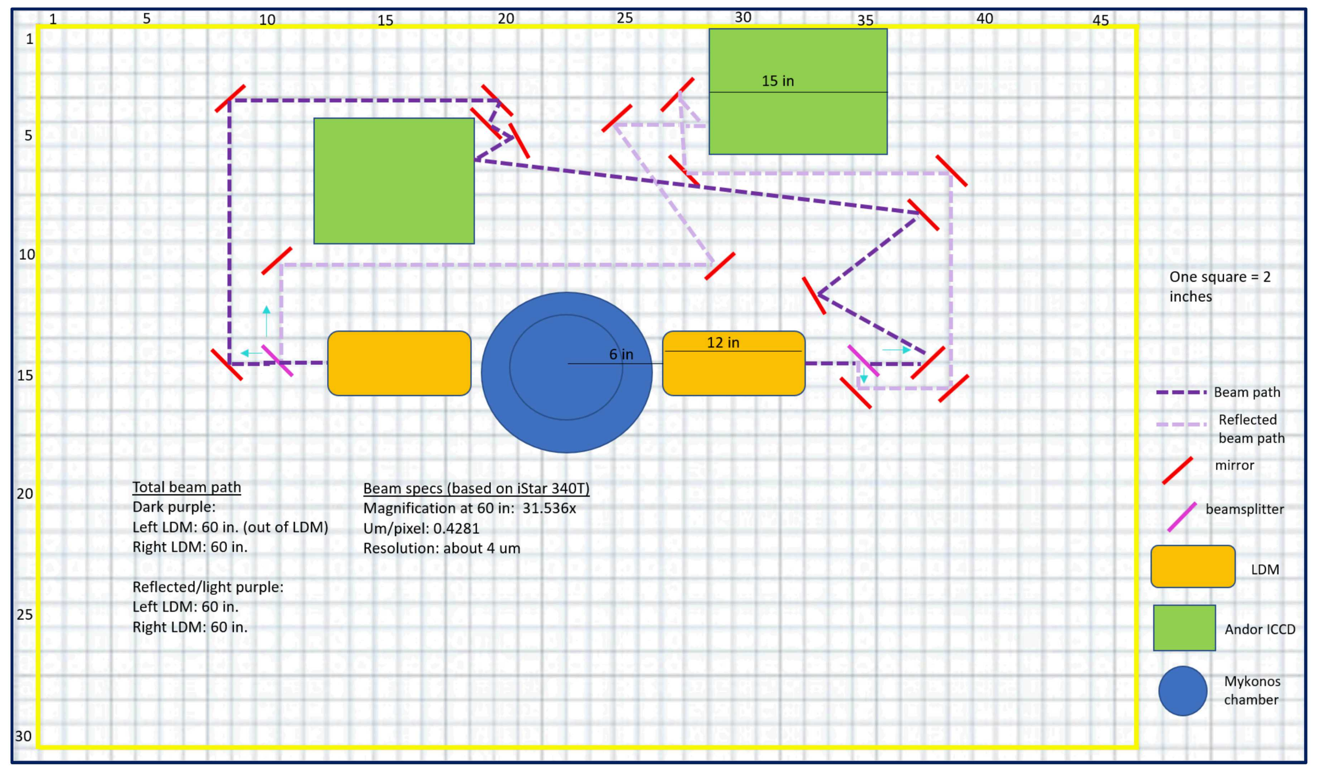
Figure b

- System magnification is currently $M = 31.25$
- Apertures have been implemented in order to block unwanted light to allow for split screen with two images
- Hadland 12-frame ICCD may replace one single-frame ICCD
- System can be easily adapted to accommodate different defect patterns

Images of front and back of test barbell, aligned side by side and taken simultaneously on both Andor iStar 340 (figure a) and Andor iStar 334 (figure b) ICCDs. Arrows indicate where images are separated.

Multi-camera splitter system will be used to procure double-sided imaging of targets

•Goal: Multi-camera splitter system will be used to simultaneously image scaled defect patterns located on the front and back sides of the target in order to monitor hot spot evolution
•Target defect patterns include two defects on each side, with sides 180° apart
•Imaging different defect patterns concurrently will reveal how strata/striations and ETI evolve
•Cameras with 2-5 ns gated exposures are required to resolve the rapid evolution of ETI driven temperature nonuniformities



Schematic of double-sided imaging optical setup

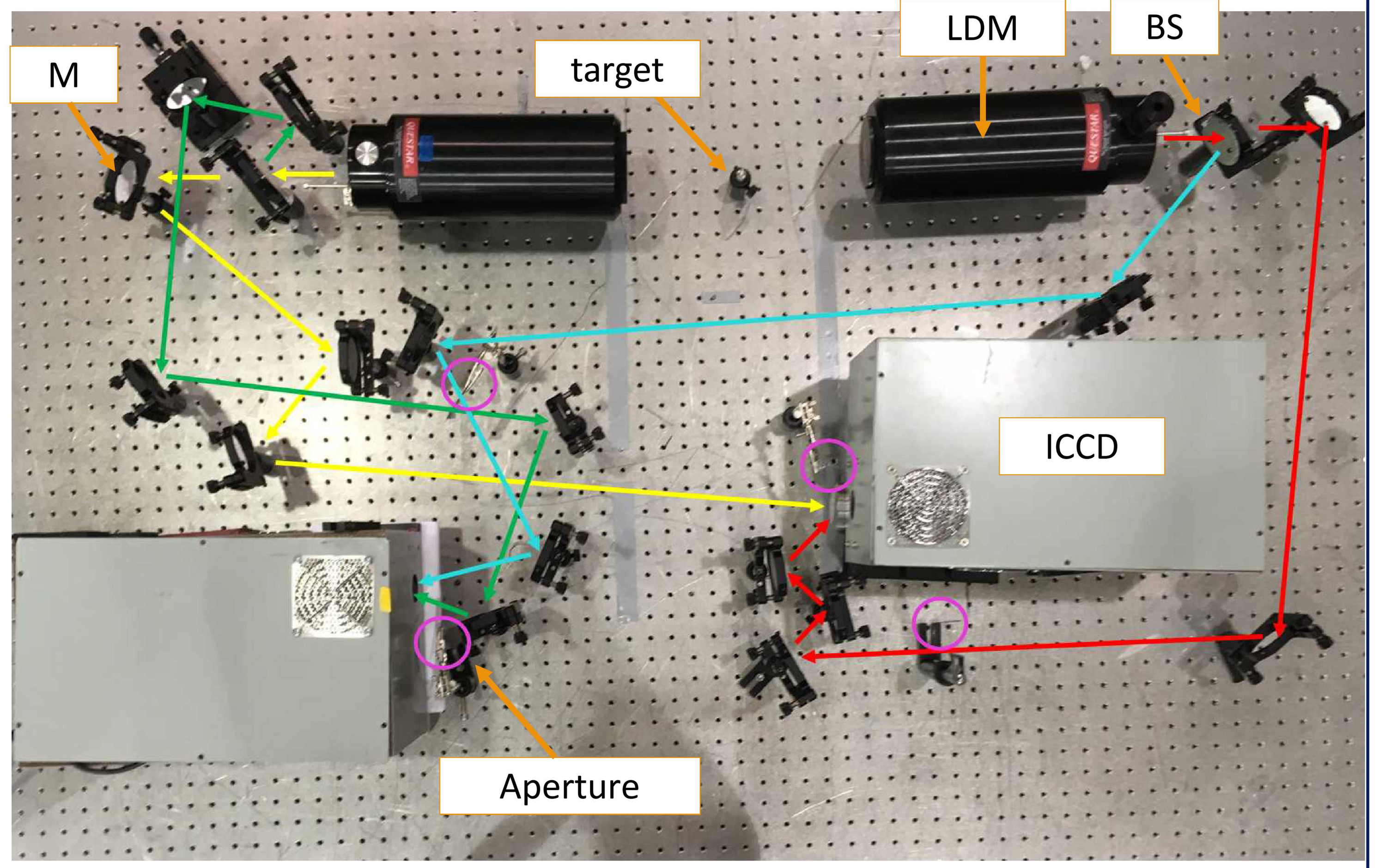
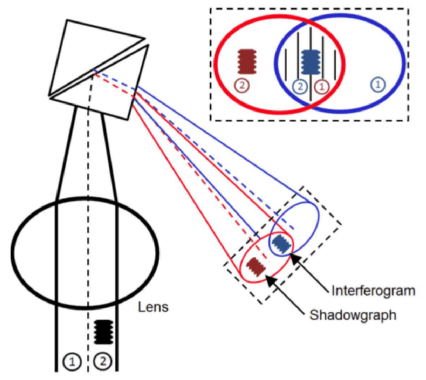


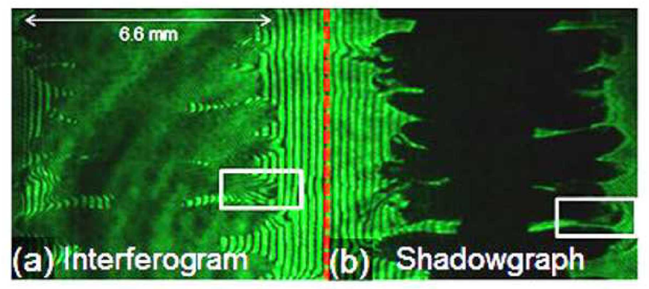
Photo of double-sided imaging optical setup

Shadowgraphy and interferometry will be implemented to diagnose plasma dynamics

- Experiments implementing shadowgraphy and interferometry using an air wedge shearing interferometer will be executed, as was done for imploding foil-liner experiments on the 1-MA Linear Transformer Driver facility at the University of Michigan.

Interferometry gives us a spatial map of electron density
- Combine a "reference" beam with a "probe" beam to produce bright/dark lines, called fringes
  - Probe beam phase shifted due to plasma
  - Reference beam passed near plasma (no phase shift)
  - Combination produces fringes due to constructive and destructive interference of light
- Our plan is to use air-wedge interferometer (as opposed to Mach-Zehnder), which gives a simultaneous interferogram and shadowgraph
- We will unfold plasma jetting from the engineered defects

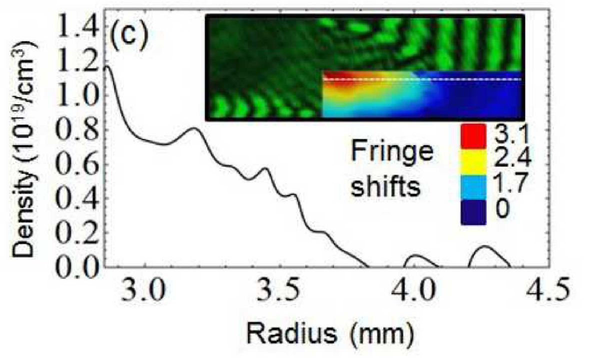




Imploding liner on MAIZE. A similar approach will be taken on Mykonos.

$$\delta = 4.46 \cdot 10^{-14} \lambda \int_0^L n_e dl.$$

Phase shift in fringes



Future work

Future work includes:
- Optimization of resolution for various target types in order to:
  - Better understand ETI/MRT
  - Improve the system by providing significant new diagnostics
- New diagnostics include high-resolution 12-frame time-gated optical imaging and laser shadowgraphy, low temperature surface emission with infrared avalanche photodiodes, streaked visible spectroscopy
- Streaked visible spectroscopy
- Detailed numerical modeling of the experiment using multiple codes, including ALEGRA 3D simulations
- Test hypotheses and observe trends by varying load materials and characteristics
- Refine, compare, and understand detailed modeling of the experiment to gain insight into fundamental physics, and learn what experimental features can be predicted or explained by modeling, and how to do so

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