Developing Technologies at General Atomics for Rep-rated Operation of High-Energy-Density-Physics Experiments

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Debris Shield Development

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Rep-rated and Low-mass Targetry

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GALADRIEL Experimental Operations

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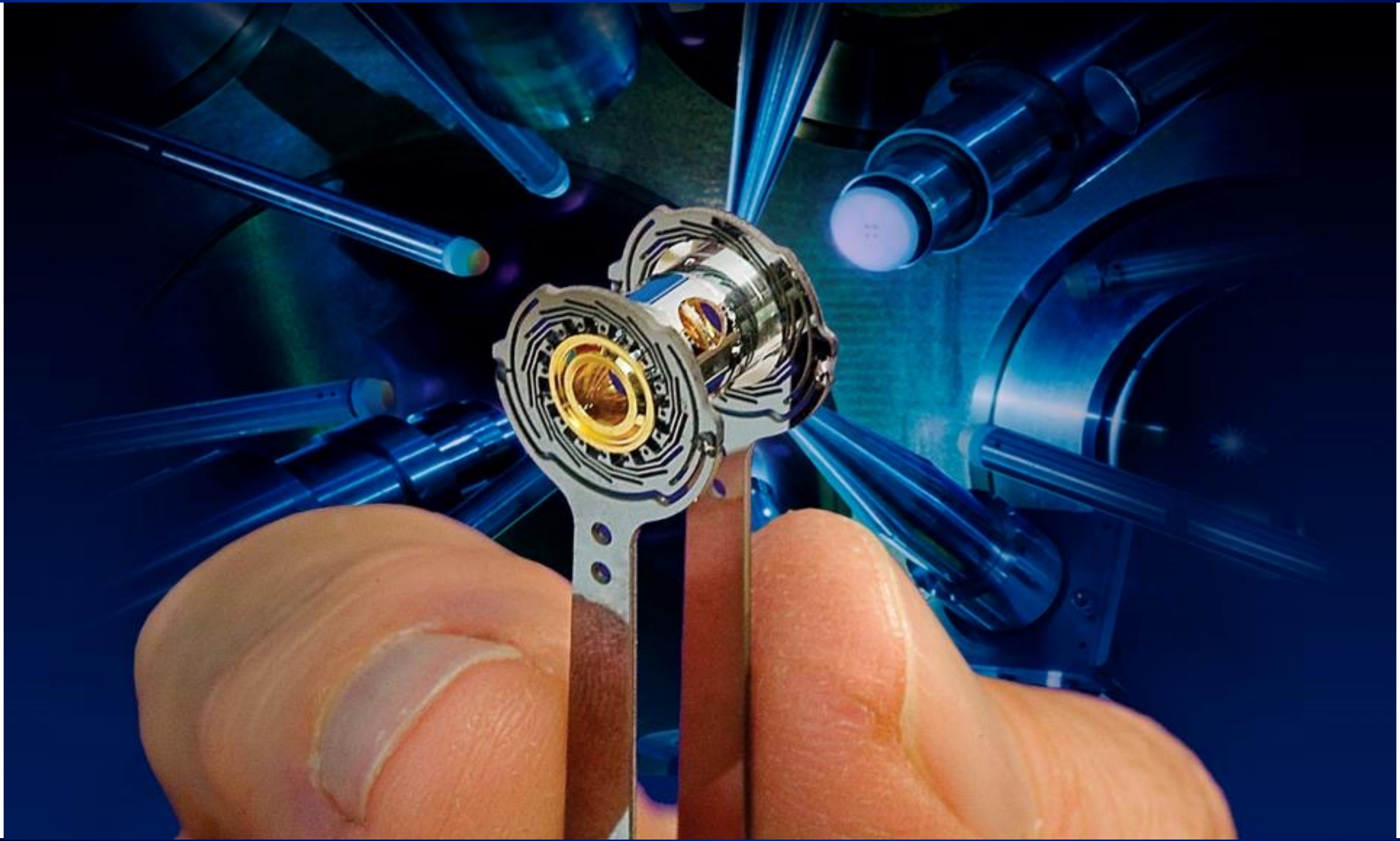
GALADRIEL Controls and Machine Learning

Mario Manuel
General Atomics

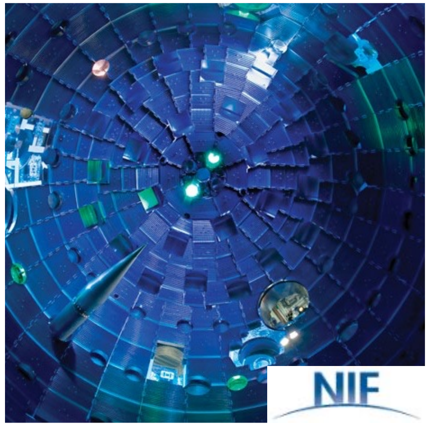
November 3, 2022
2022 Extreme Light Infrastructure User Meeting

Inertial Fusion Technology (IFT)

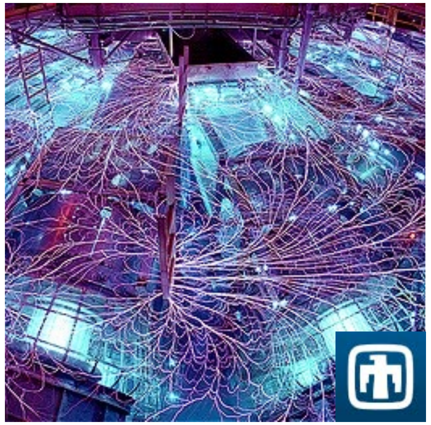
Supporting High Energy Density Science Through Target Fabrication and Engineering Solutions



IFT produces 'targets' for NNSA's three Major ICF Science Facilities



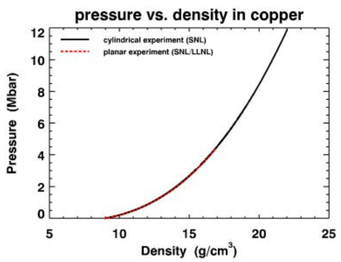
National Ignition Facility



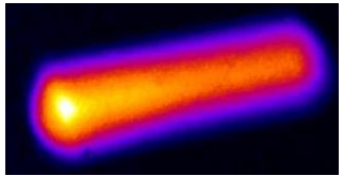
Z pulse power machine

OMEGA & EP laser facilities

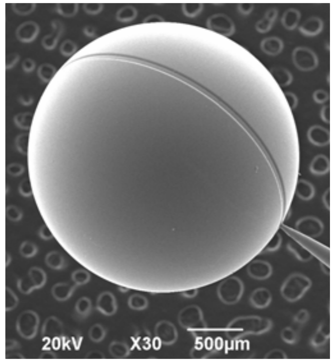
Material Properties



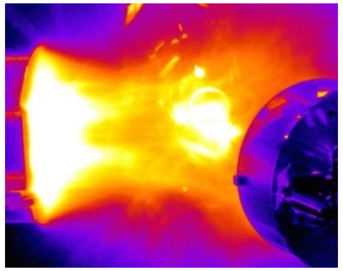
Radiation Transport



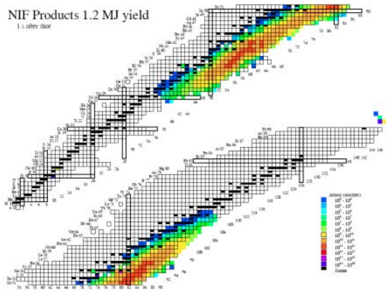
Engineering Feature



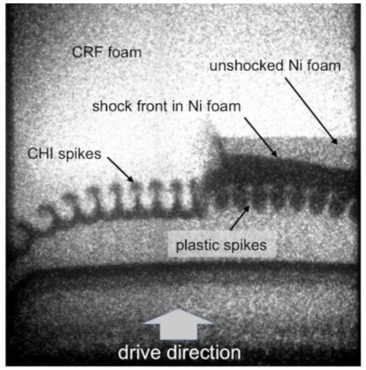
Output & Effects



Radiochemistry



Hydrodynamics

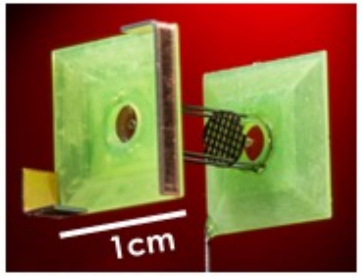


>30,000 ft² (>2700 m²) of lab space
>110 technical staff

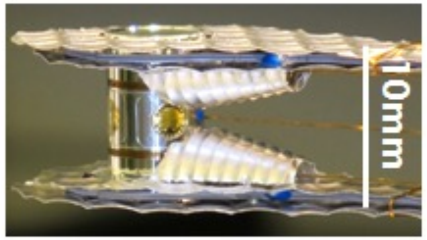
GA has provided target and engineering solutions for 31 years

Engineering: Cryogenic & Insertion Systems

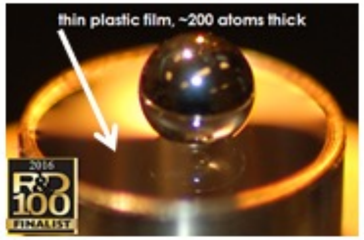
Targets are Experimental Platforms

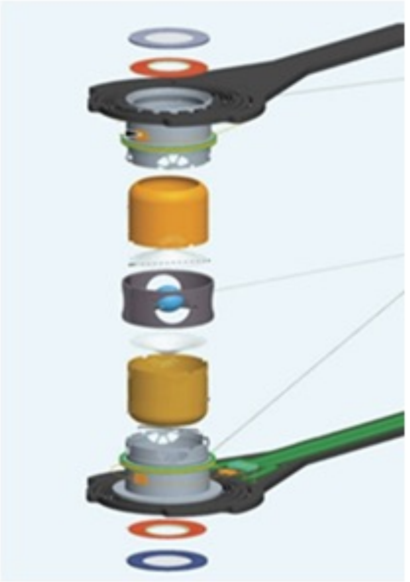


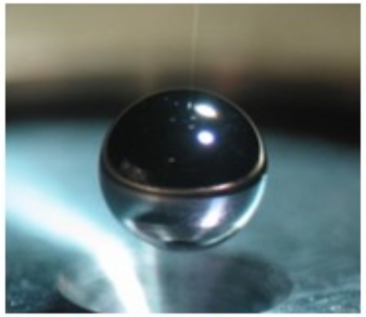
Science target



Ignition target



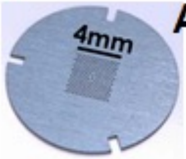




2mm dia. beryllium shell

Engineering: Innovative Diagnostic Capabilities

10 ps camera



Aperture arrays

SLOS diagnostic

GA provides unique R&D for targets and diagnostics

Innovative multi-disciplinary materials and fabrication R&D coupled with operations excellence

- Extensive coating, synthesis, and fabrication facilities
- Engineered microstructures and properties
- Small lot R&D fabrication
- Precision characterization
- Custom equipment and instrumentation development

Projects presently underway relevant to rep-rated HED

- **Debris shields**
  - Plastic membranes, ~2-3um thick, with open apertures up to ~51cm diameter
- **Target deployment**
  - Rastered targets, ELI-Beamlines tape-drive system
- **Large-volume and low-mass targets**
  - 2PP technology on tape-drive targets
- **Rep-rated diagnostics and controls (GALADRIEL)**
  - GA LAboratory for Developing Rep-rated Instrumentation and Experiments with Lasers
  - 1TW (~25mJ in ~25fs,) at 800nm at up to 10Hz
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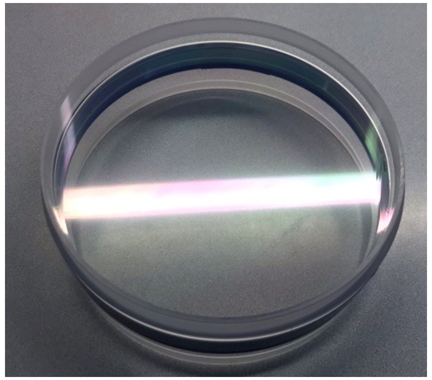
  - Control feedback using diagnostic output (LWFA using e-spec, SHWS at 0.1Hz)

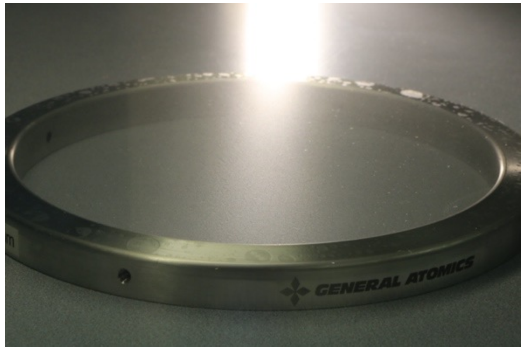
We are developing large debris shields for large laser systems

- **Debris shields are "pellicle"-like optics**
  - Thin polymer membrane affixed to a circular frame/hoop
    - ~2-4 microns thick
- **LULI optics lab conducted initial tests on R&D prototypes with various films**
  - Polymer film A had very little polarization effects (good for debris shield)
  - Polymer film B had strong polarization effect (good for waveplates)
    - Reproducibility being assessed
    - Looking to see if there is sufficient community interest develop ½ or ¼ waveplates
- **R&D prototypes have been sent to RAL for on-laser tests**
- **Production prototypes have been produced with ID's of 22 cm and 51 cm**



R&D Prototype
ID 20.3 cm

51 cm ID Production
Prototype

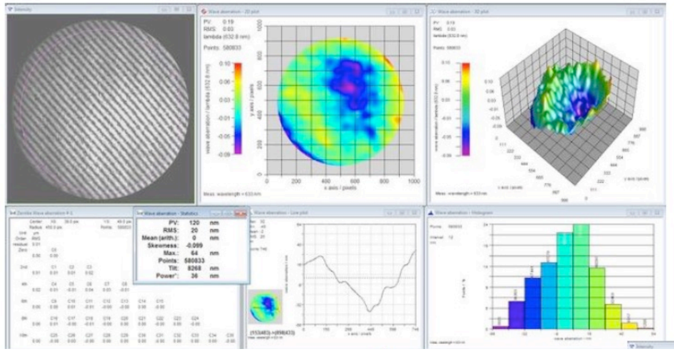


22 cm ID
Production
Prototype

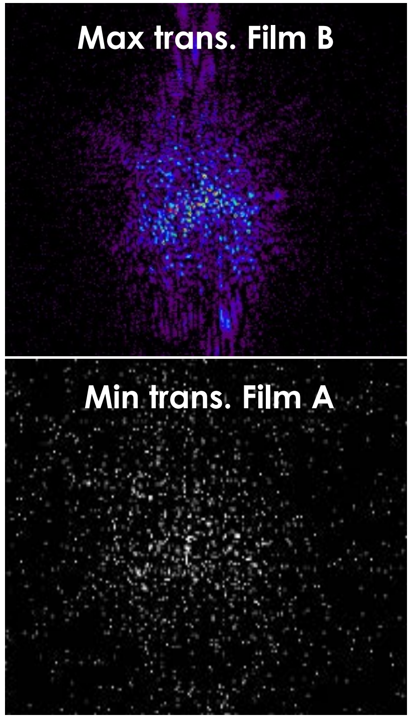
LULI optics lab conducted several measurements on the R&D prototypes

- Wavefronts measured with Zygo, 150 mm diameter sample region
- Alterations to wavefront is minimal/acceptable and is between λ/5 - λ/8
- Spectral changes measured with CARY 60
- Polarization measured with LULI designed device
- Focal spot aberrations measured with LULI designed device

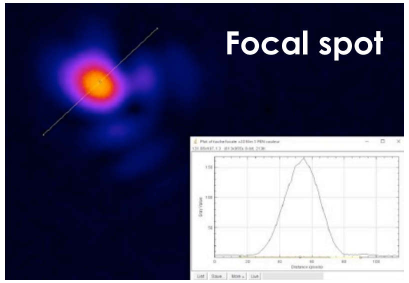
R&D film	Zygo Wavefront PV (nm)	Wavefront RMS (nm)	Spectral changes in transmission (650-950 nm)	Polarization *relative* to B#2 (%)	Focal spot aberrations (@ 804 nm)
Polymer film A#1	120	20	-	9	-
Polymer film A#2	130	22	82% - 99% (WL dep.)	4	-
Polymer film B#1	134	22	82% - 99% (WL dep.)	66	85%
Polymer film B#2	96	18	82% - 99% (WL dep.)	100	85%



Wavefront



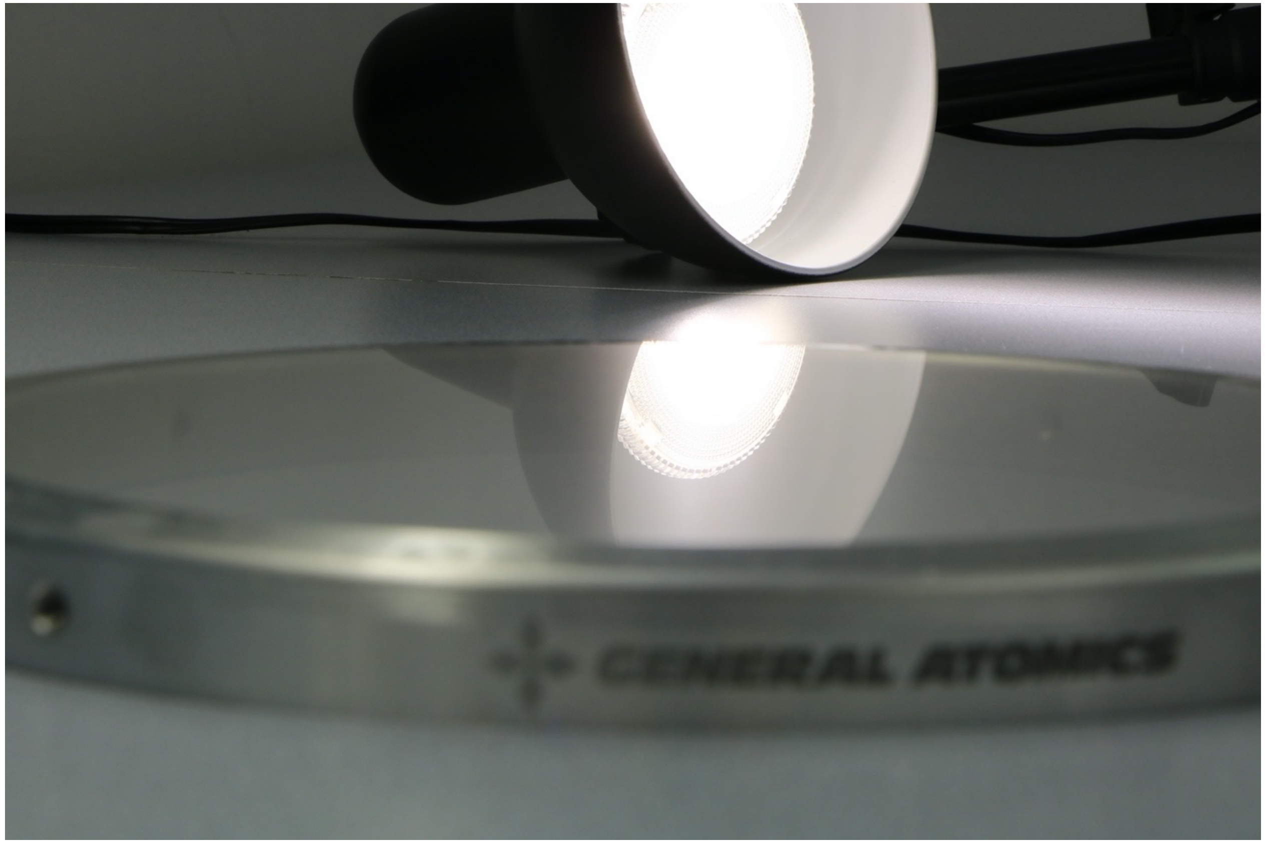
Polarization between crossed polarizers

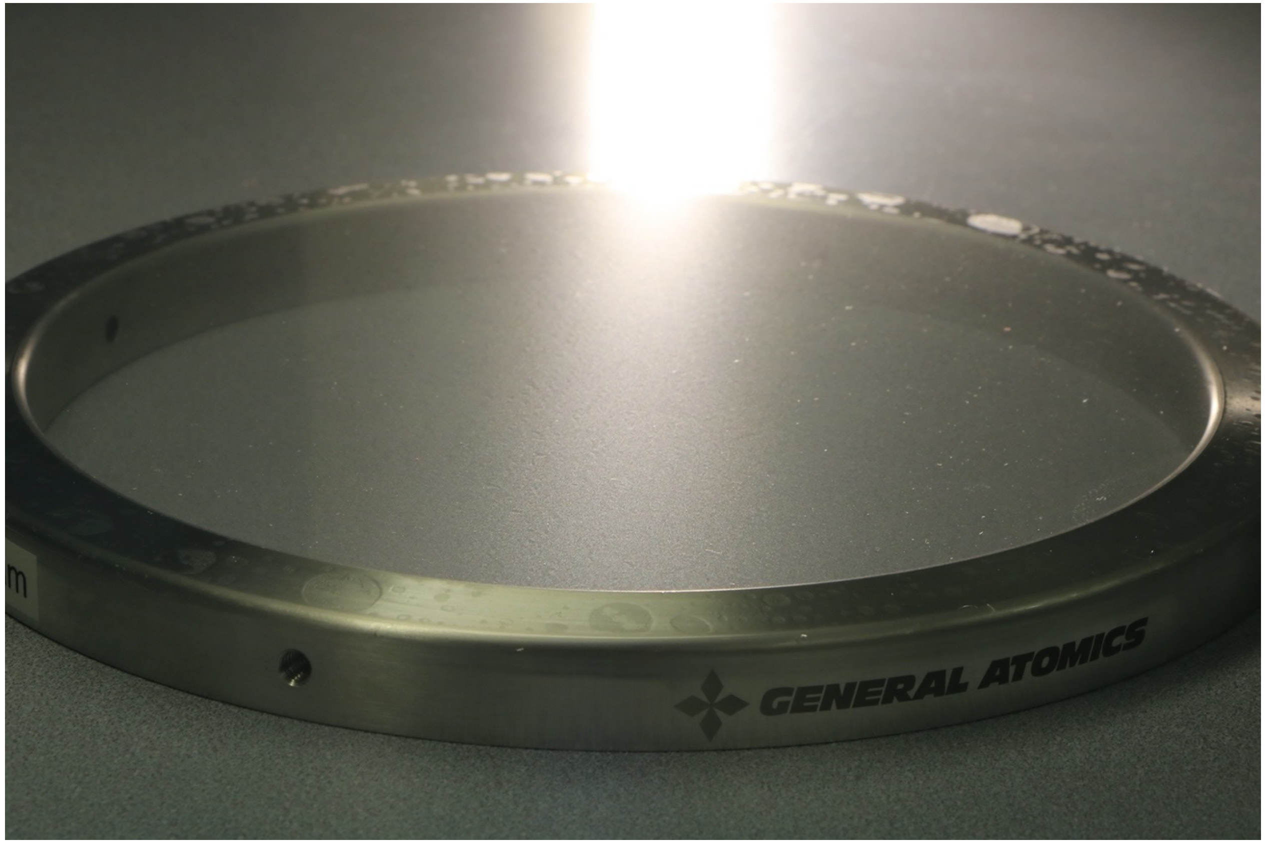


Manufacturing testing

- **Assembly process developed**
- **Plan for recycling rings**
  - Ship used rings back to GA for cleaning and new film
  - How do we clean and recertify for use into the vacuum chamber again?
  - Outgassing test?
    - Aluminum ring, Film, Embedded debris?
- **Separate assembly fixtures made for accommodating different film widths:**
  - 62 cm wide films (Polymer A film for debris shields)
  - 50 cm wide films (Polymer B films for wave plates)
    - Potential for ¼ and ½-wave plates if there is sufficient interest to manufacture film at the precise thickness

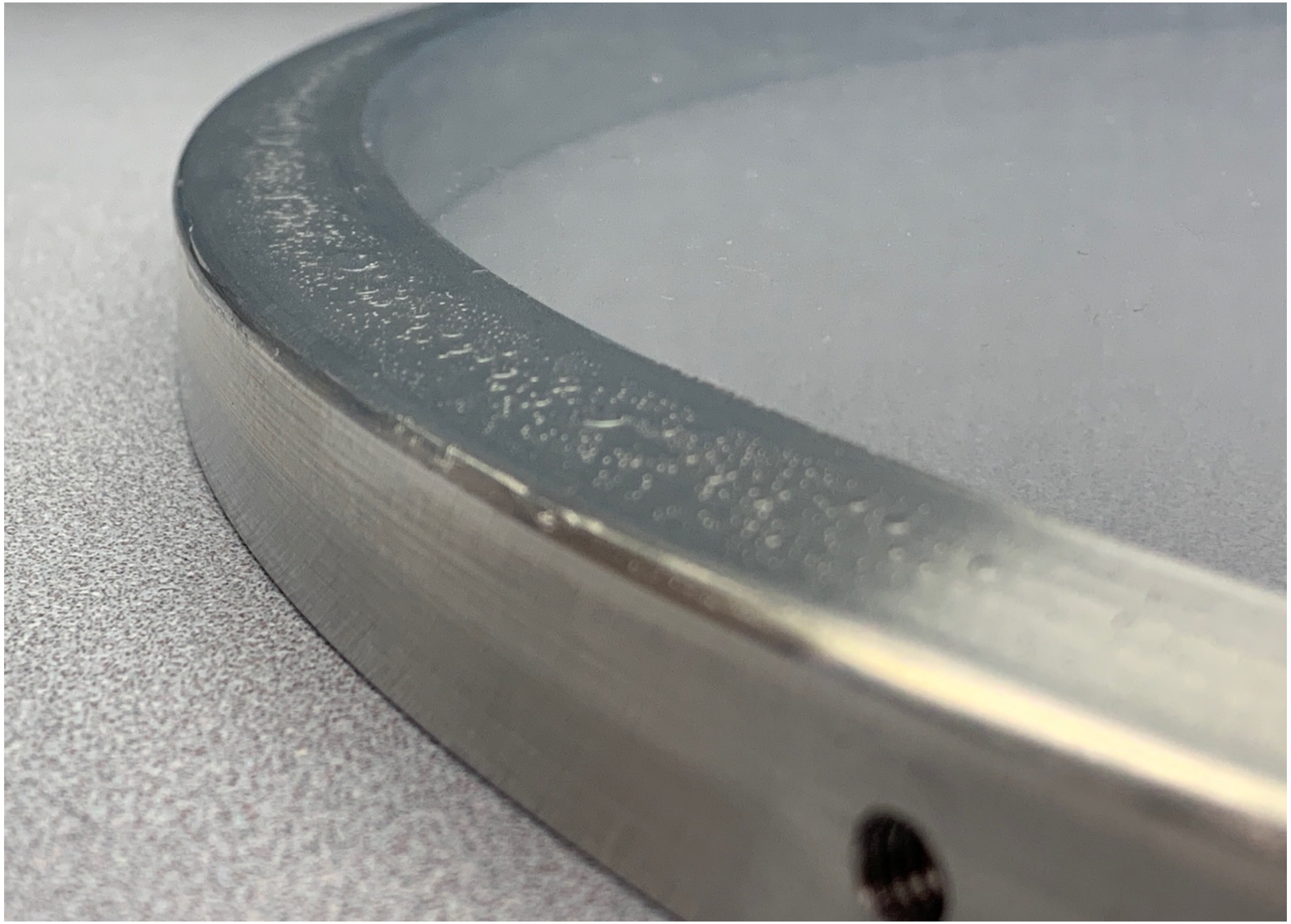
Debris shield production prototypes made with 22 cm open aperture

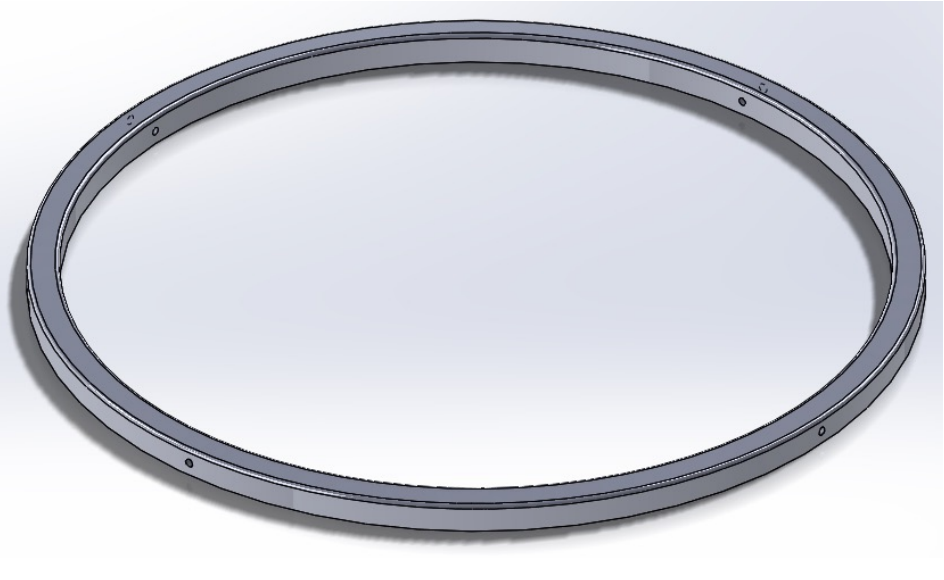




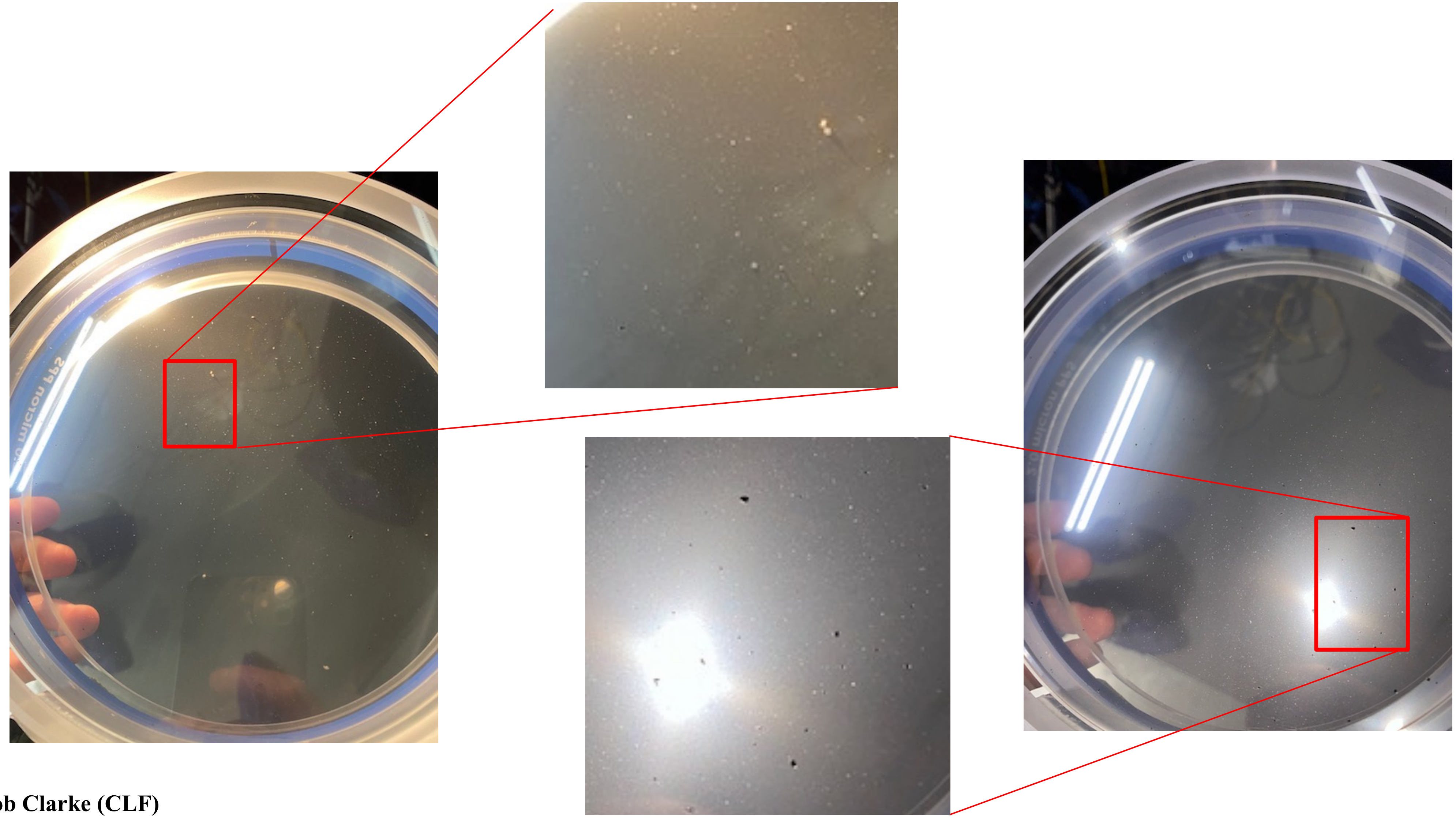
Debris shield production prototypes made with 51 cm open aperture

Debris shields have threaded side holes to facilitate shipping and handling





CLF debris tests* at Gemini shooting solid targets



* Images from Rob Clarke (CLF)

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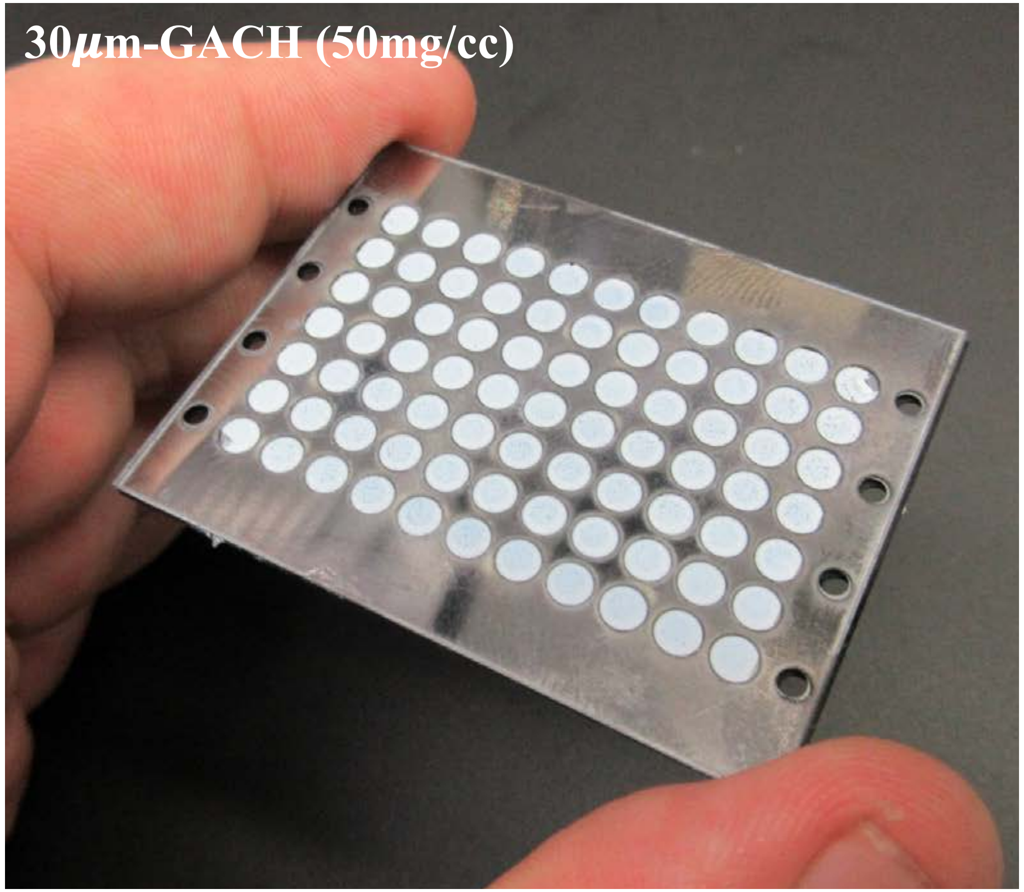
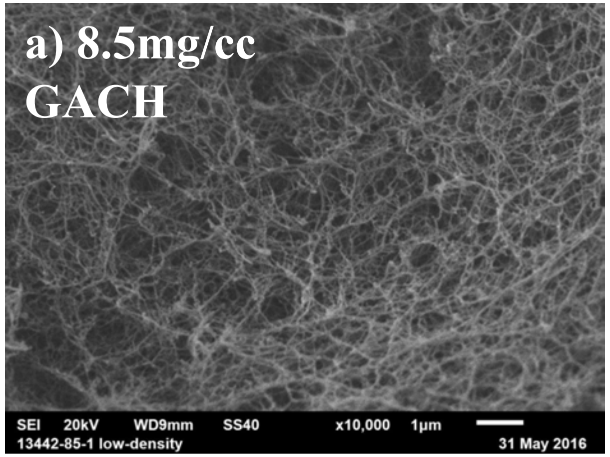
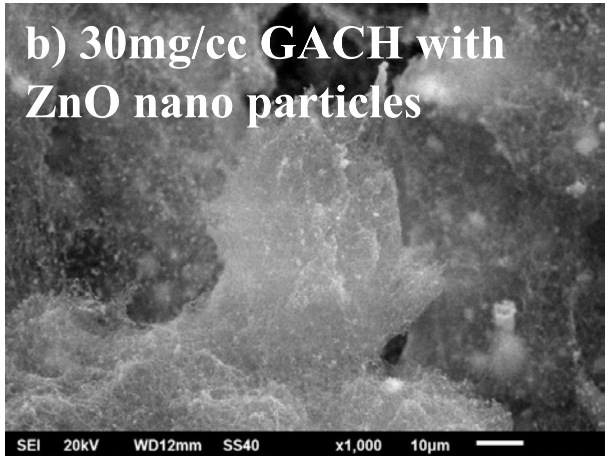
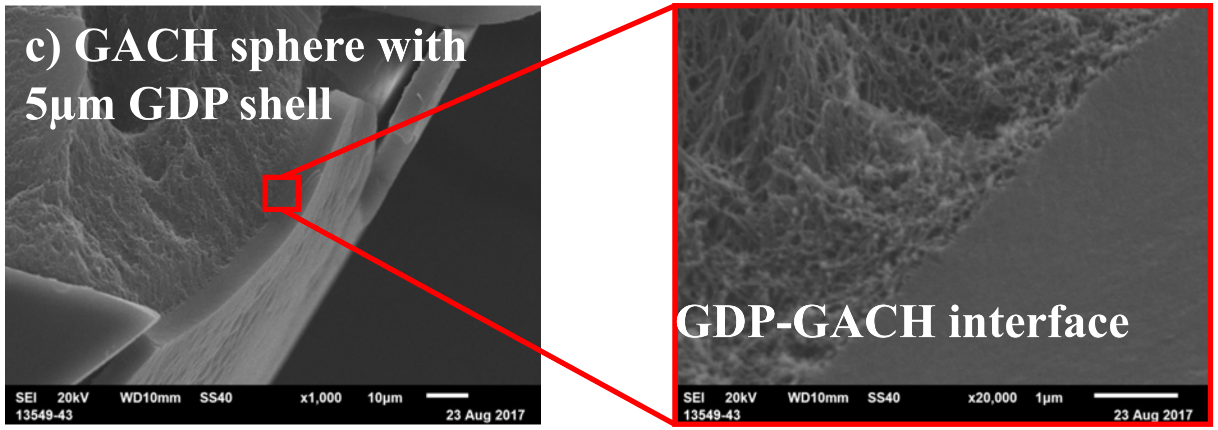
Low-density foams in raster plates

Rastered Targets

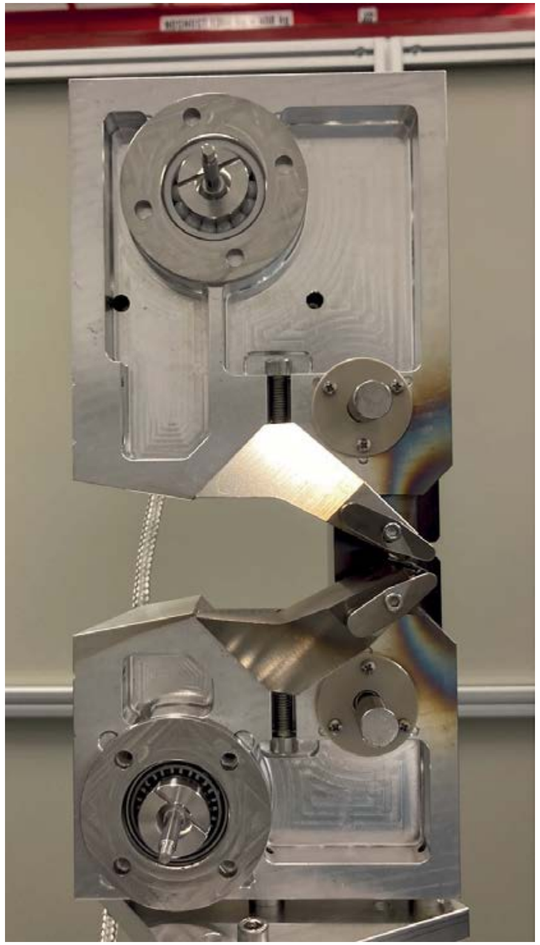


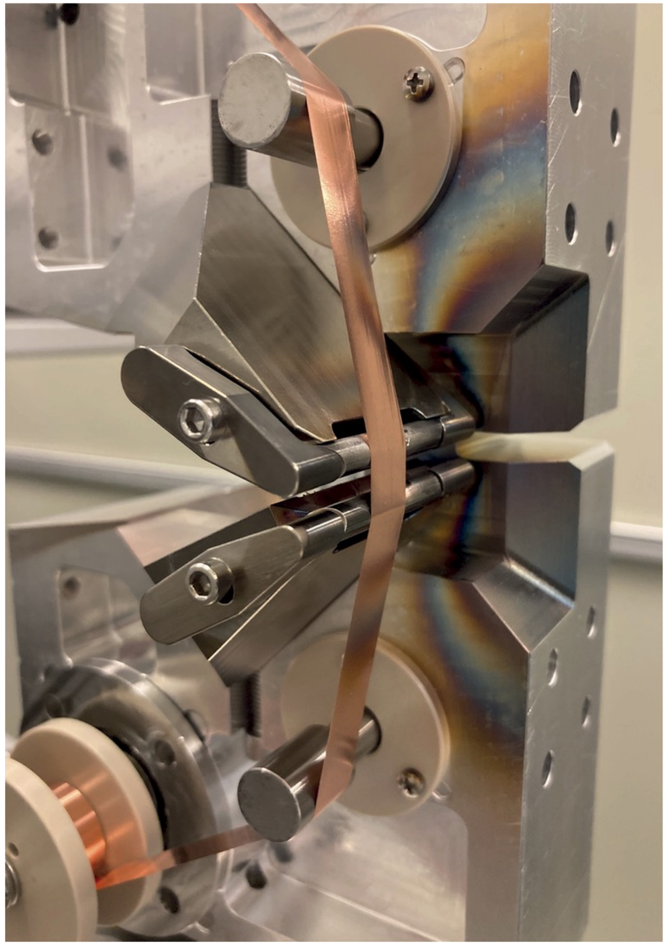


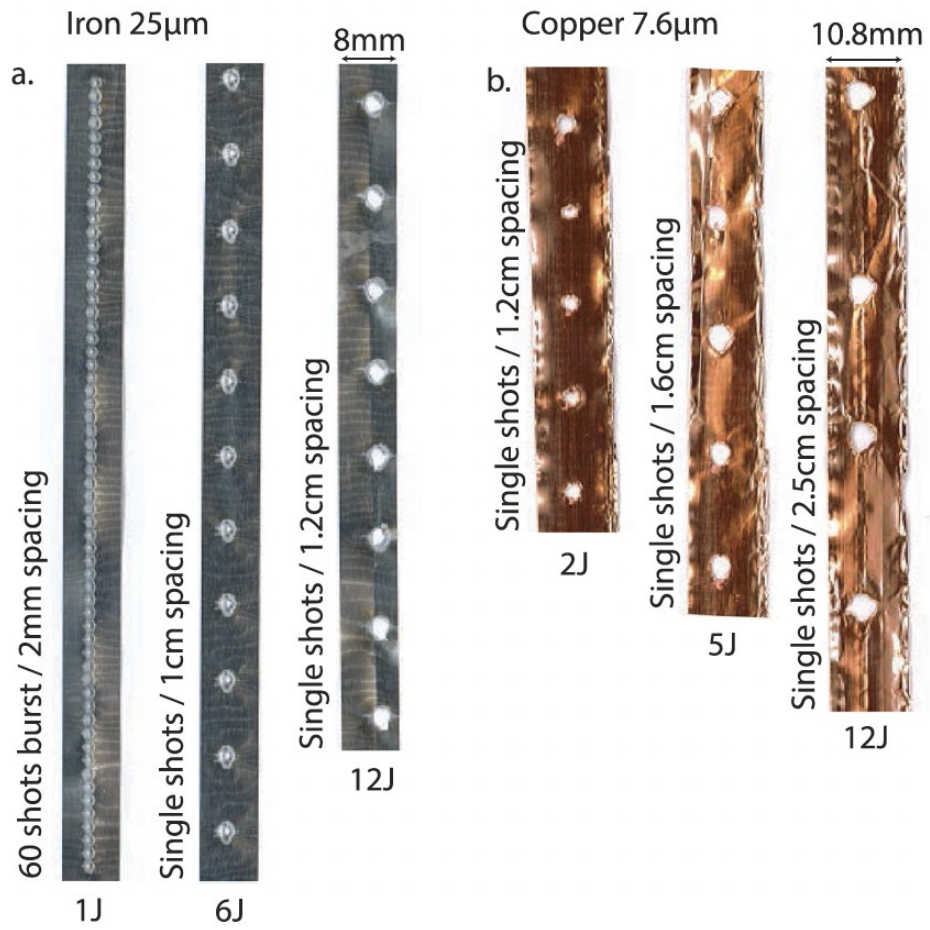




ELI-Beamlines tape-drive system







*Condamine, RSI 92 (2021)

GENERAL ATOMICS

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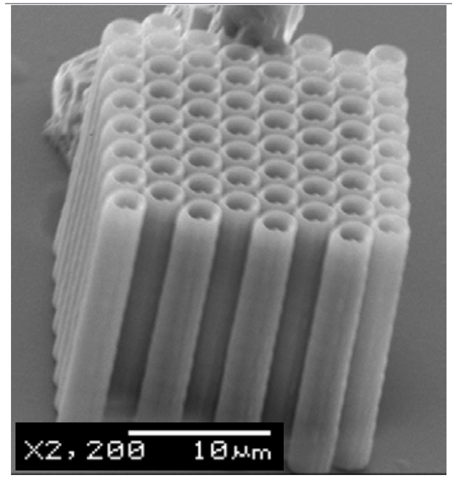
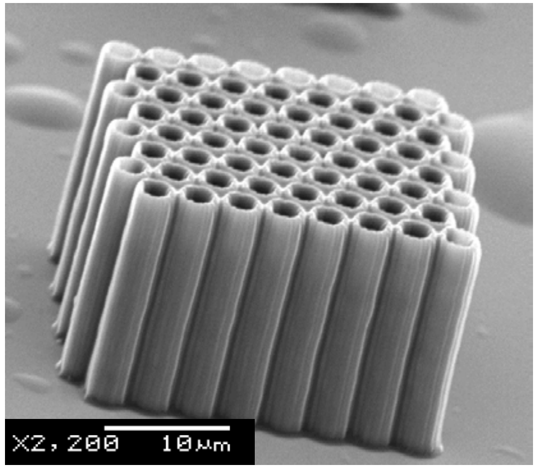
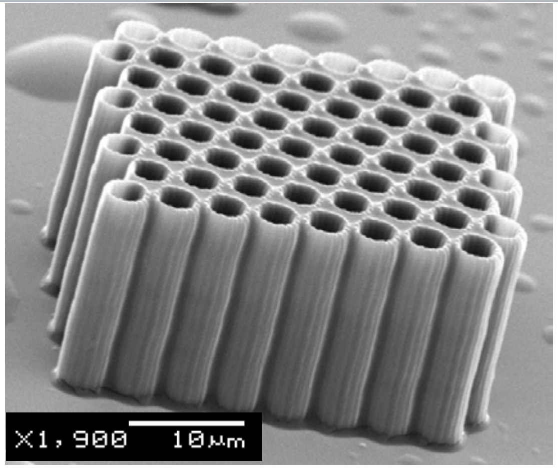
2PP-printed tube structures on flat substrates



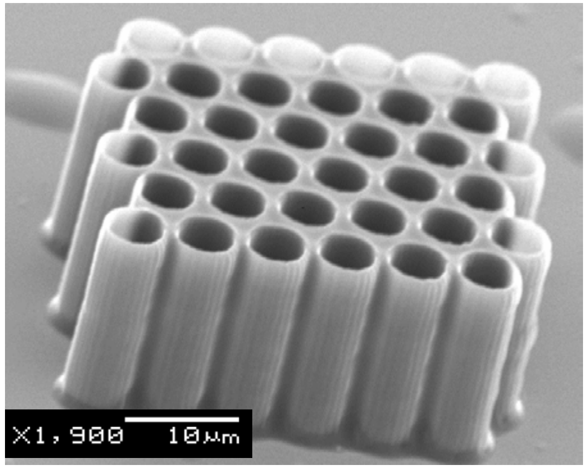
1 µm ID, 20 µm Tall



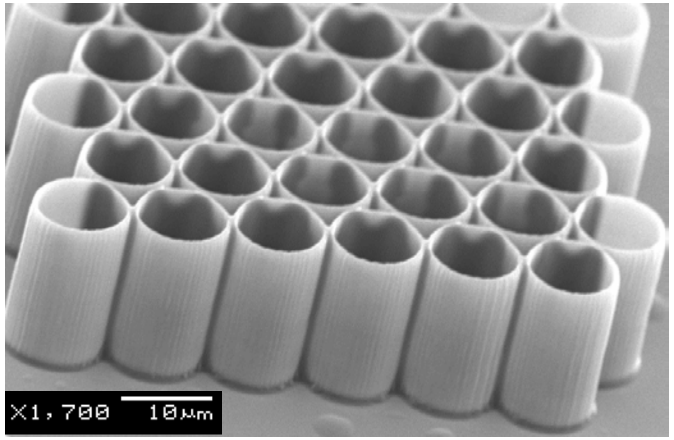
2µm ID, 20 µm Tall



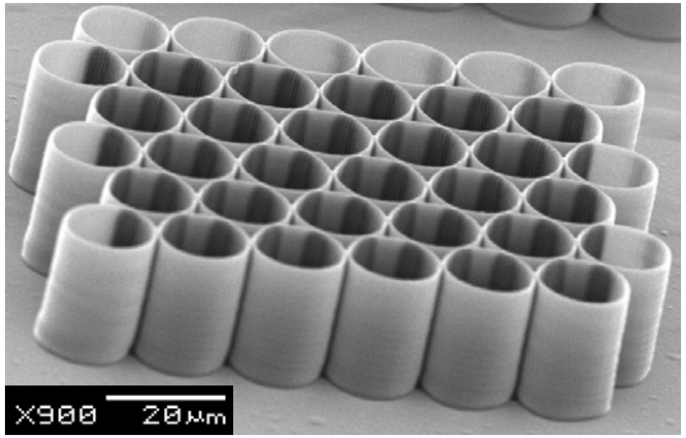
3µm ID, 20 µm Tall



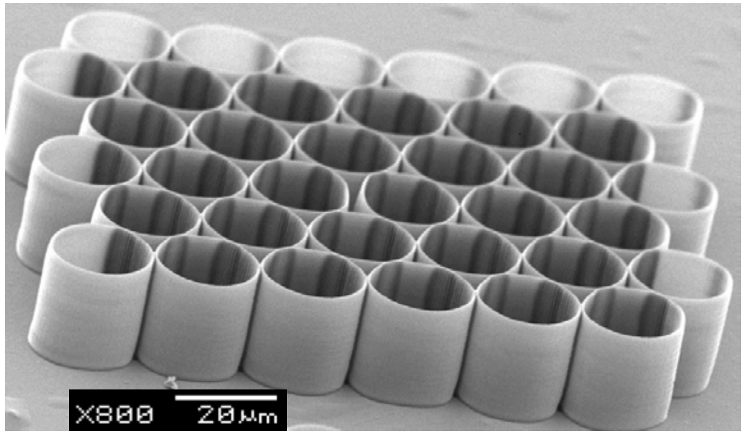
5µm ID, 20 µm Tall



10 µm ID, 20 µm Tall

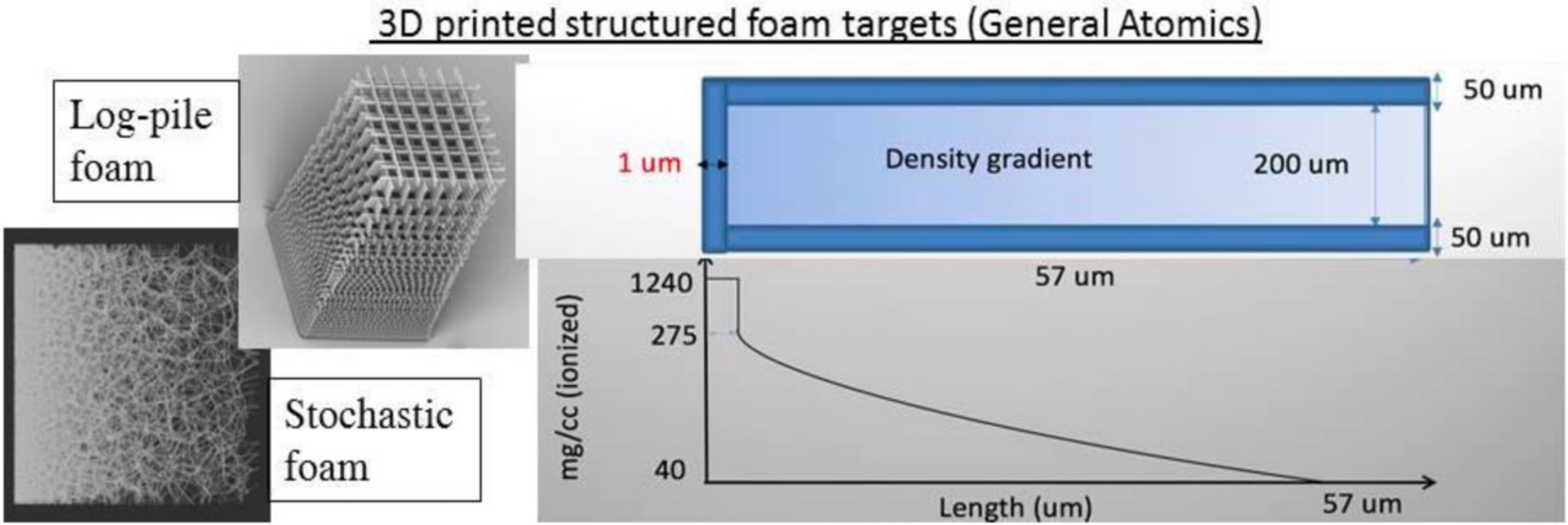


15 µm ID, 20 µm Tall

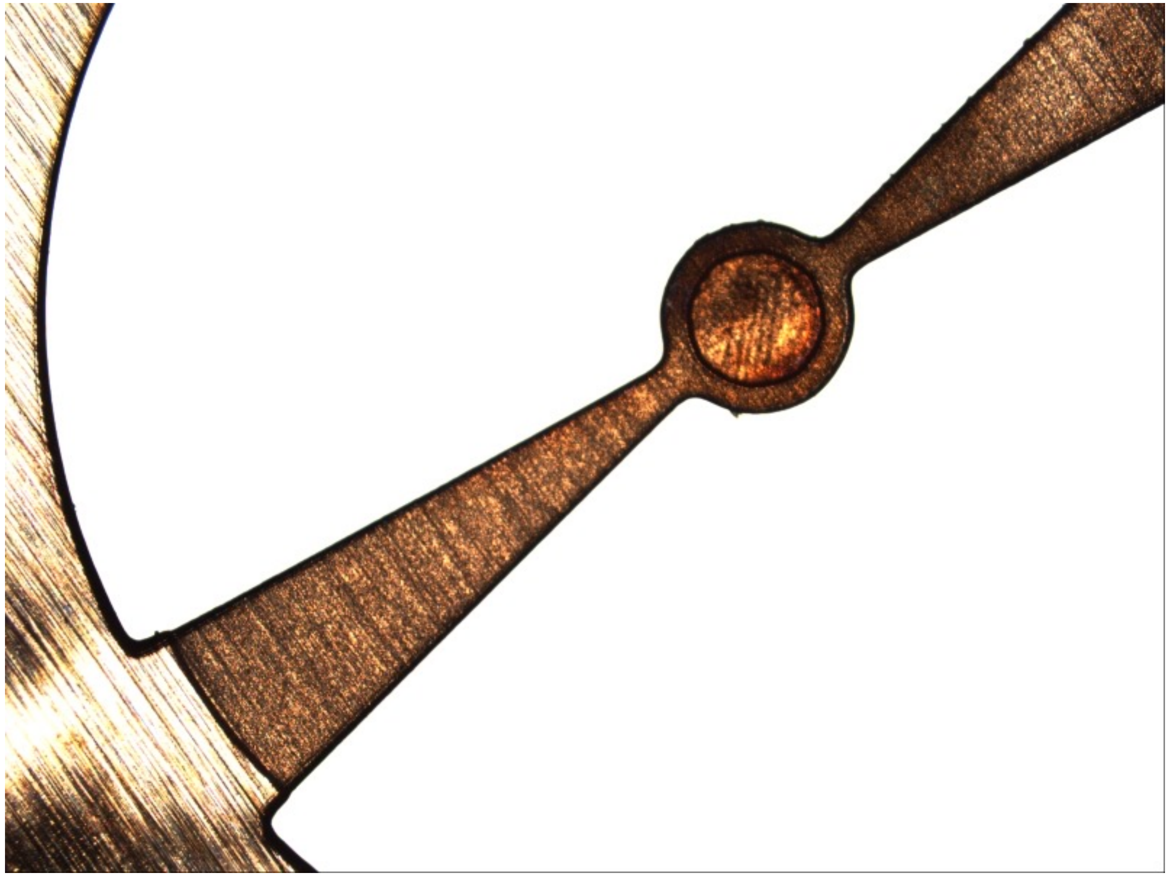


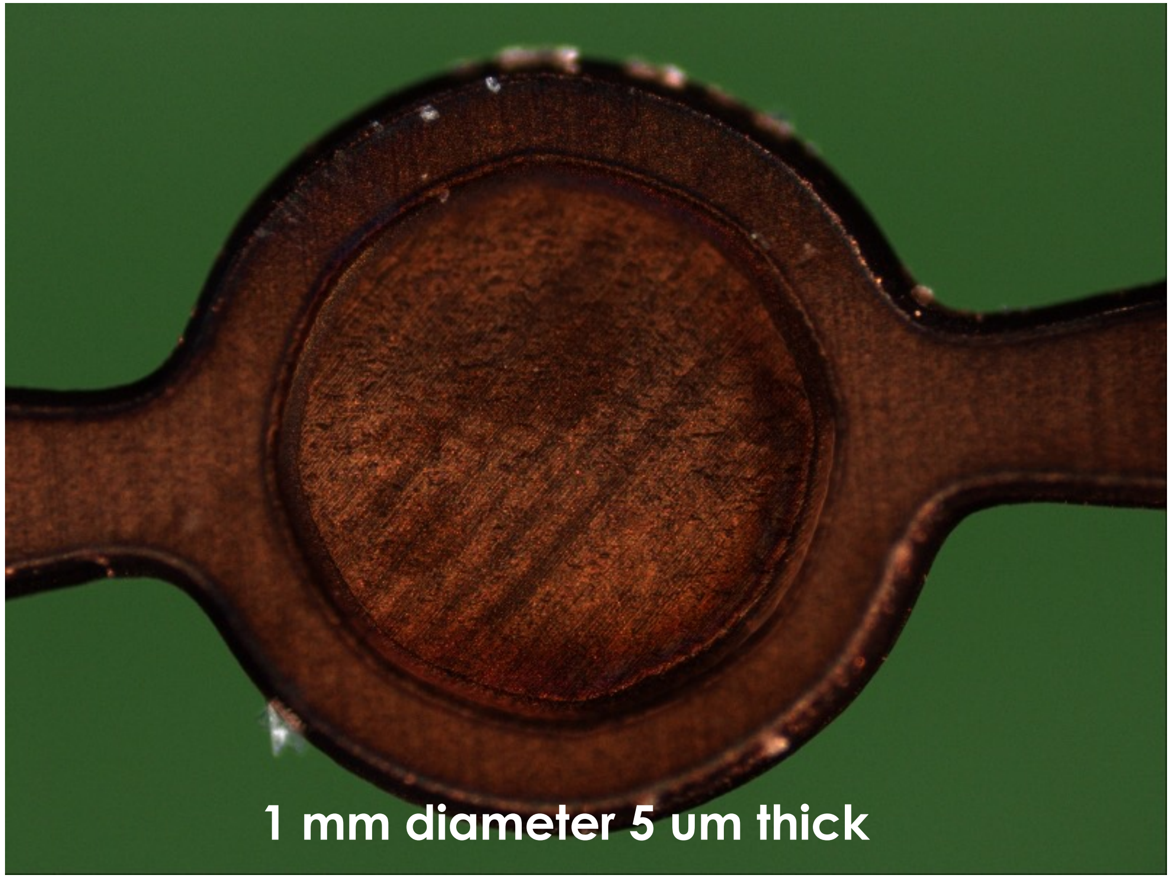
20 µm ID, 20 µm Tall

2PP-printed ‘foams’ with tailored density profiles



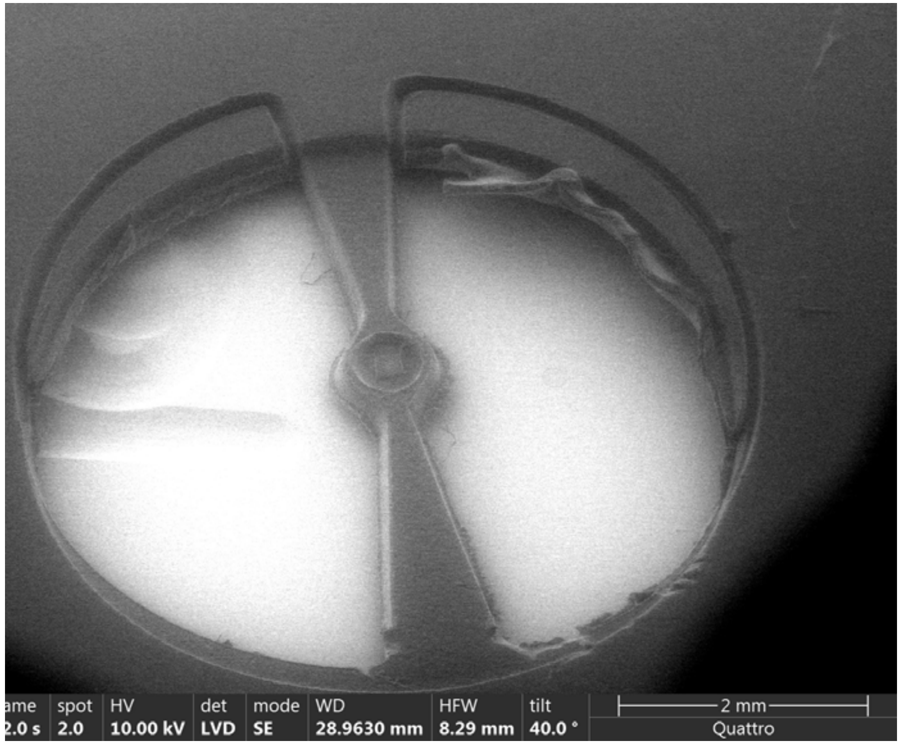
Low-mass copper targets ~5um-thick on copper ribbon

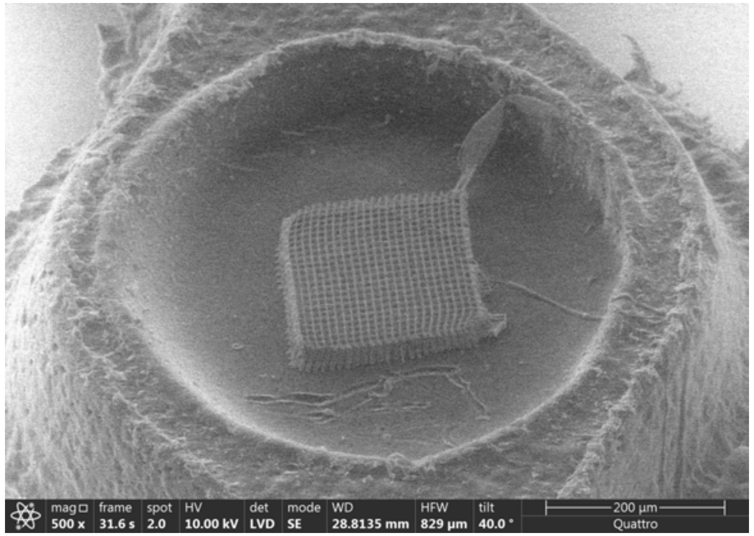


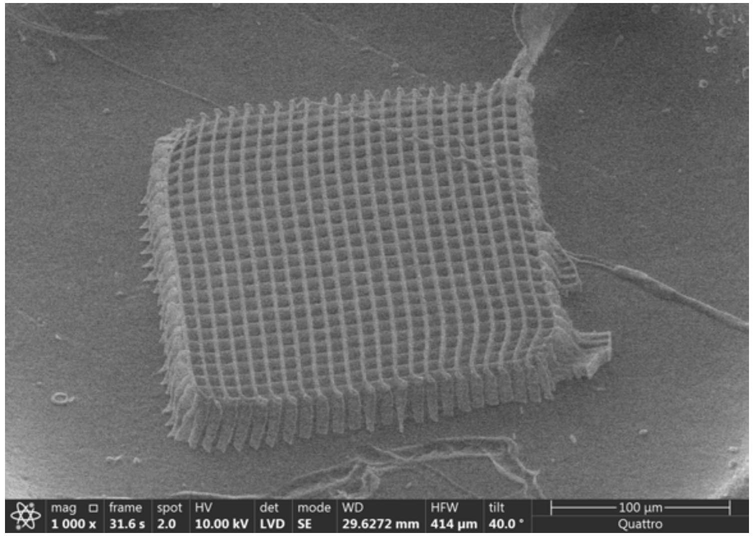


GENERAL ATOMICS

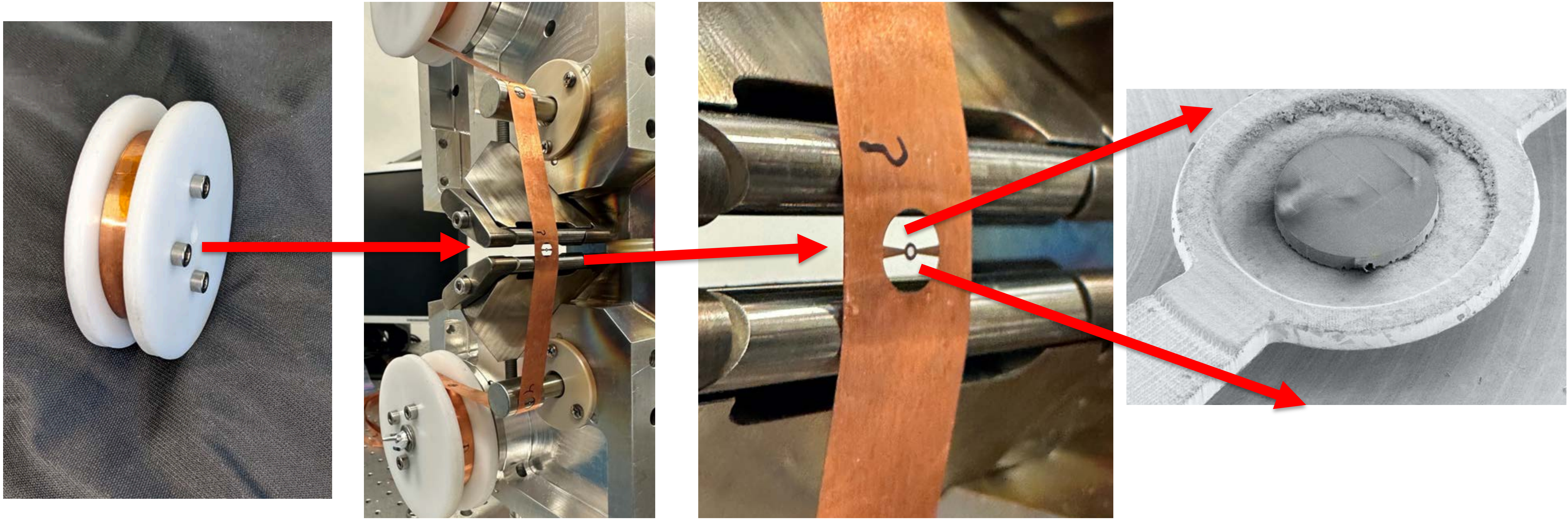
2PP-printed tube structures on ~30um-thick plastic ribbon







GA aperture-tape holds complex and rigid 3D structures, mitigates ablation debris, and can be flexed, rolled, and transported



First demonstration shots using L4n executed in November 2022

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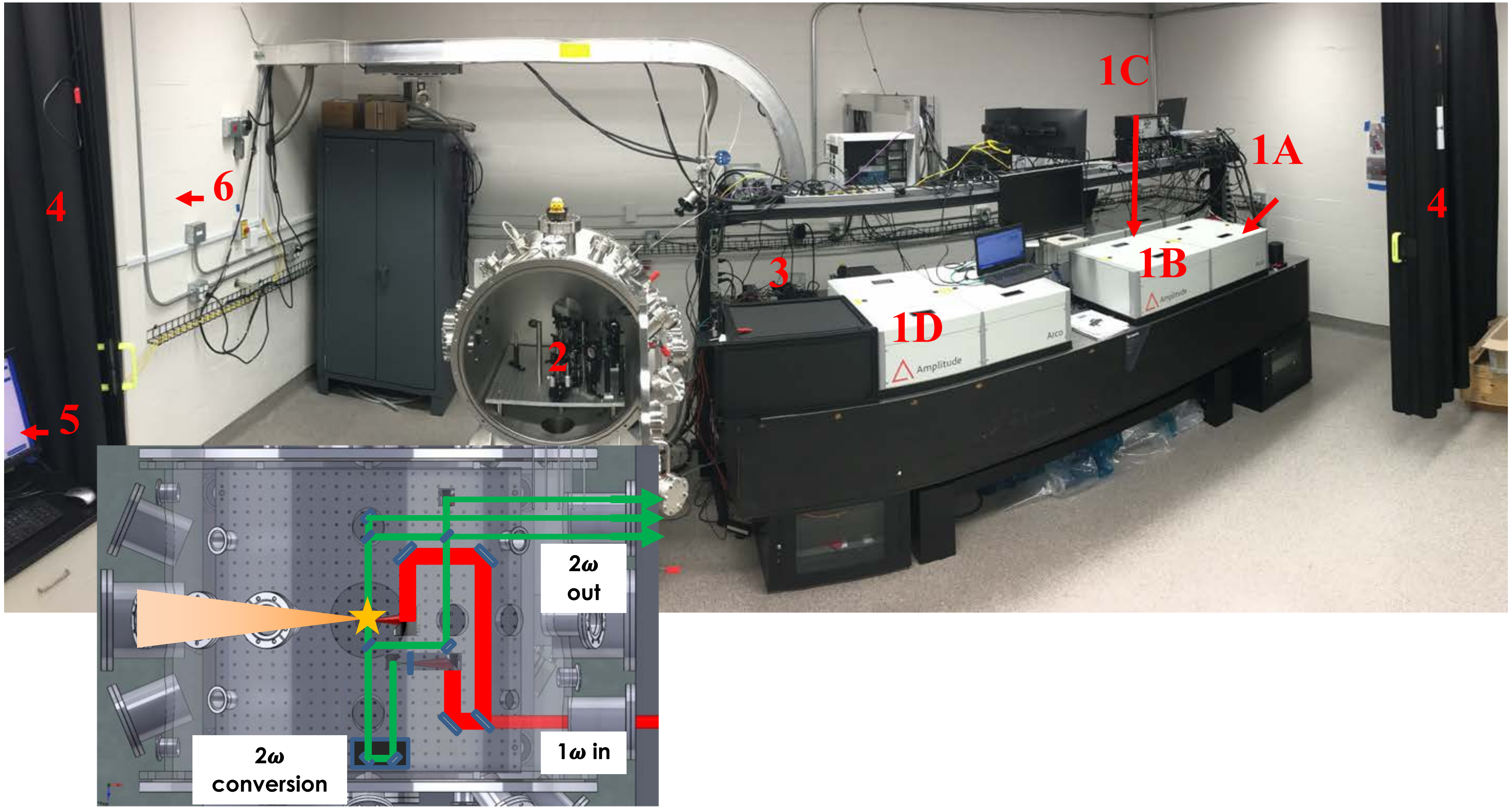
GA LAboratory for Developing Rep-rated Instrumentation and Experiments with Lasers

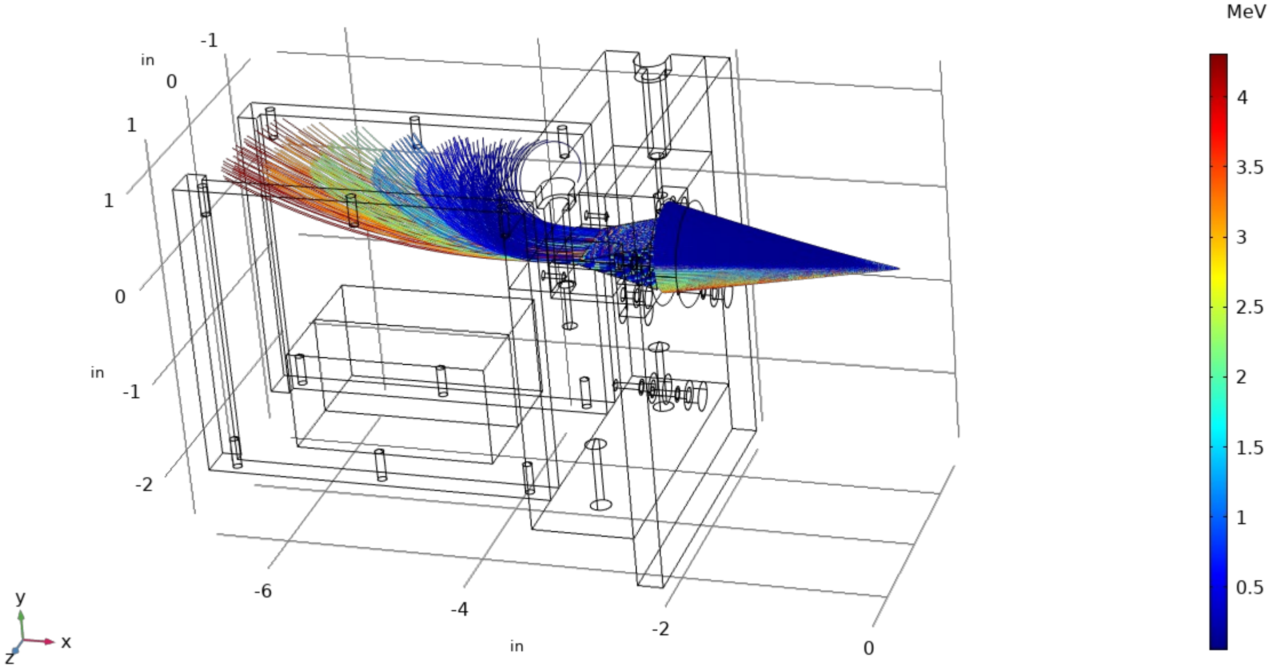


1. ARCO X Laser
   A. Oscillator
   B. Stretcher
   C. Amplifiers
   D. Compressor
2. Target Chamber
3. Laser Diagnostics
4. Laser curtains
5. Control terminal
6. Gas/pump systems

Electron and x-ray spectrometers to begin algorithm and controls development using 'simple' spectral data

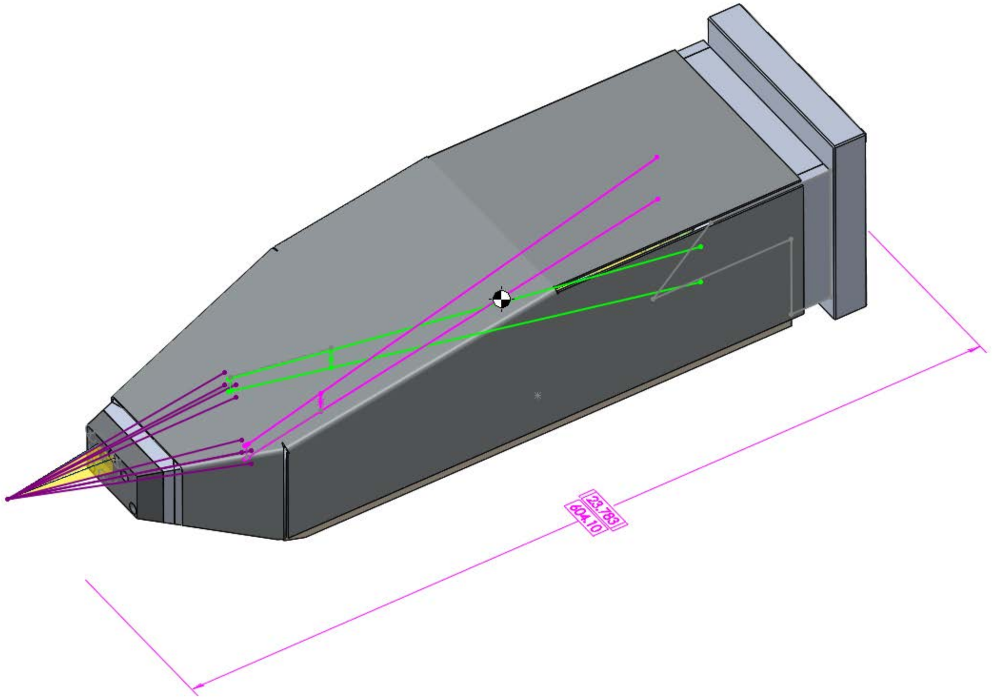
Electron Spectrometer

➢ **Magnet-based design coupled to a scintillator and CMOS sensor.**



X-ray Spectrometer

➢ **Transmission-crystal design coupled to a scintillator and CMOS sensor**



GENERAL ATOMICS

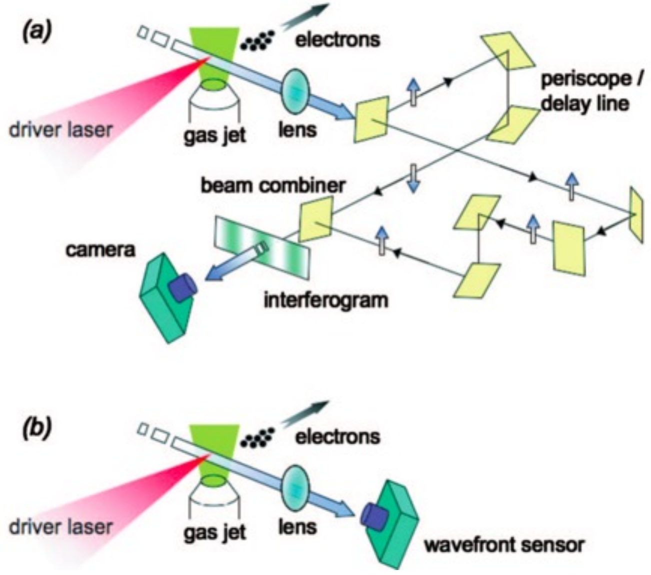
Shack-Hartman Wavefront Sensor (SHWS) as a replacement for imaging interferometry

Angle of refraction in a plasma

Electron density

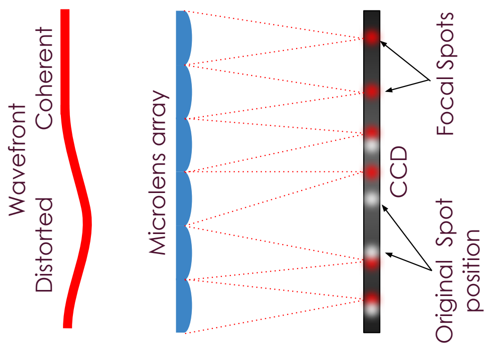
$$\theta = \frac{1}{2}\int \frac{\nabla(n_e)dx}{n_{cr}}$$

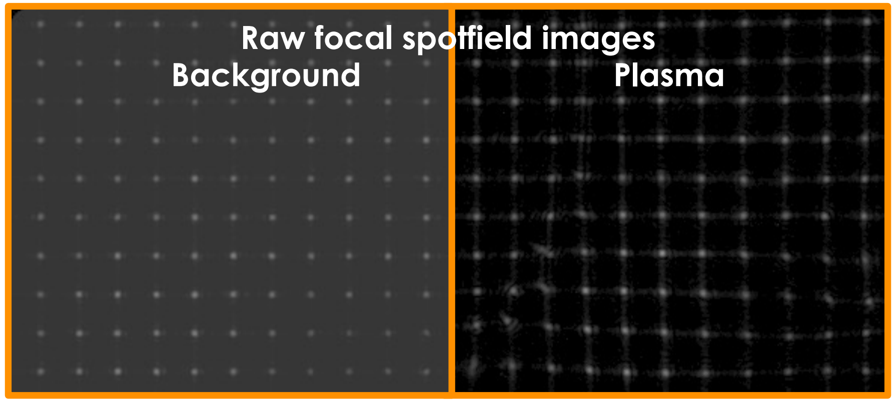
Critical density



Comparison of a) Mach-Zehnder interferometer and b) SHWS setups.[5]

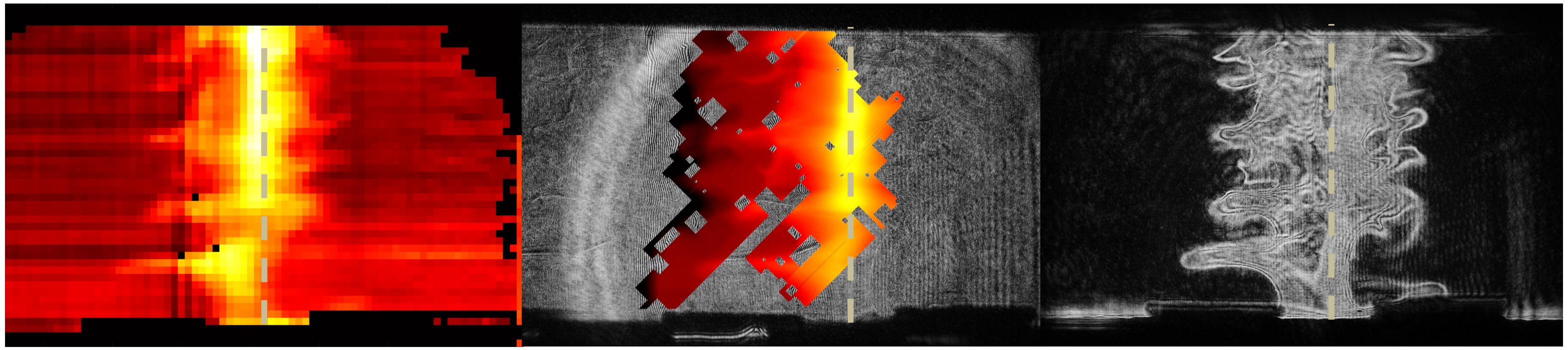
Side view of SHWS





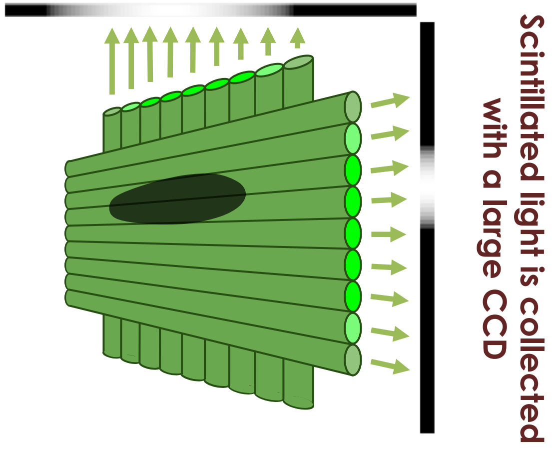
- ➢ Significantly simpler setup than interferometry, smaller dataset, and lighter analysis
- ➢ Currently using a Thorlabs WFS-40-K2:
  - ➢ Two MLAs: f = 14.6 and 5.2 mm
- ➢ Tested on D_2 gas-puff Z-pinches: Good qualitative and quantitative agreement between SHWFs, Mach-Zehnder interferometry, and schlieren imaging.

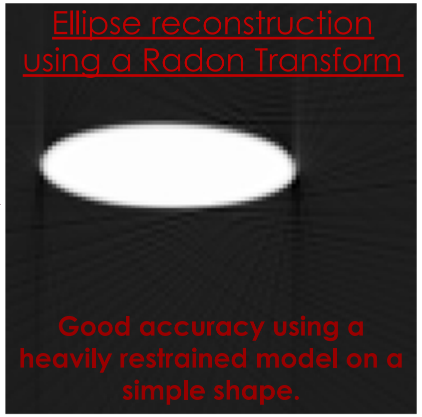
SHWFs (f = 5.2mm MLA) | Mach-Zehnder Interferometer | Schlieren

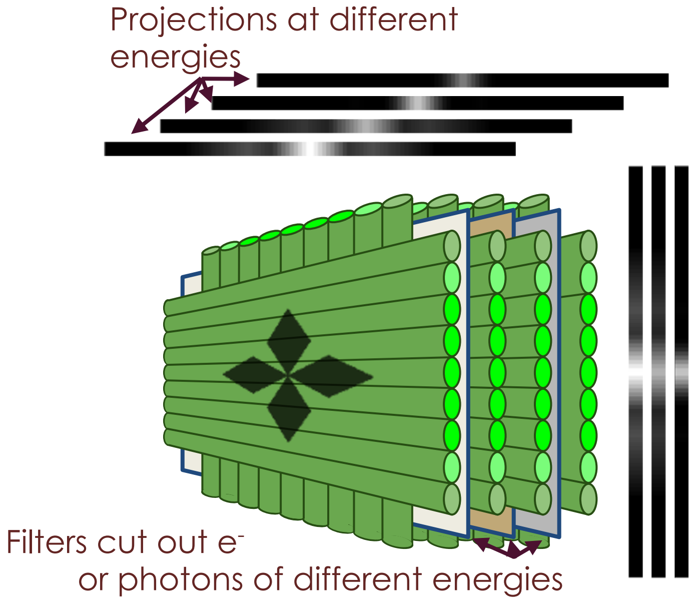


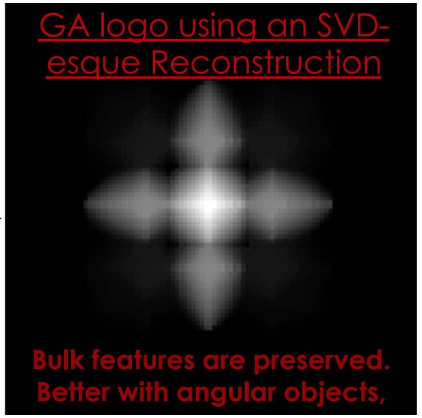
GENERAL ATOMICS

Scintillating fiber-based beam profiler using orthogonal 1D projections









➢ **Various reconstruction methods include:**

Radon Transform: fast, well documented, works best with more data or assumptions.

Singular Value Decomposition (SVD): Fast, solves Ax = b with many penalizing/ weighting methods.

Ridge Regression, etc: coefficient estimates improve accuracy, but significantly slower.

➢ **Presently studying the behavior of the fiber arrays in terms of fiber-to-fiber and inter-layer transport of scintillated light.**

Projects presently underway relevant to rep-rated HED

- **Debris shields**
  - Plastic membranes, ~2-25um thick, with open apertures up to ~51cm diameter
- **Target deployment**
  - Rastered targets, ELI-Beamlines tape-drive system
- **Large-volume and low-mass targets**
  - 2PP technology on tape-drive targets
- **Rep-rated diagnostics and controls (GALADRIEL)**
  - GA LAboratory for Developing Rep-rated Instrumentation and Experiments with Lasers
  - 1TW (~25mJ in ~25fs,) at 800nm at up to 10Hz
  - Diagnostics: Low-energy e-spec, beam profiler, SHWS, x-ray spec, comp. imag.
  - Control feedback using diagnostic output (LWFA using e-spec, SHWS at 0.1Hz)