



High resolution fiber imaging for pulsed power experiments

K.W. Fulford^{a,b}, D. A. Yager-Elorriaga^a, S. Patel^a, M. M. Montoya^a, T. Ao^a, M. A. Gilmore^b

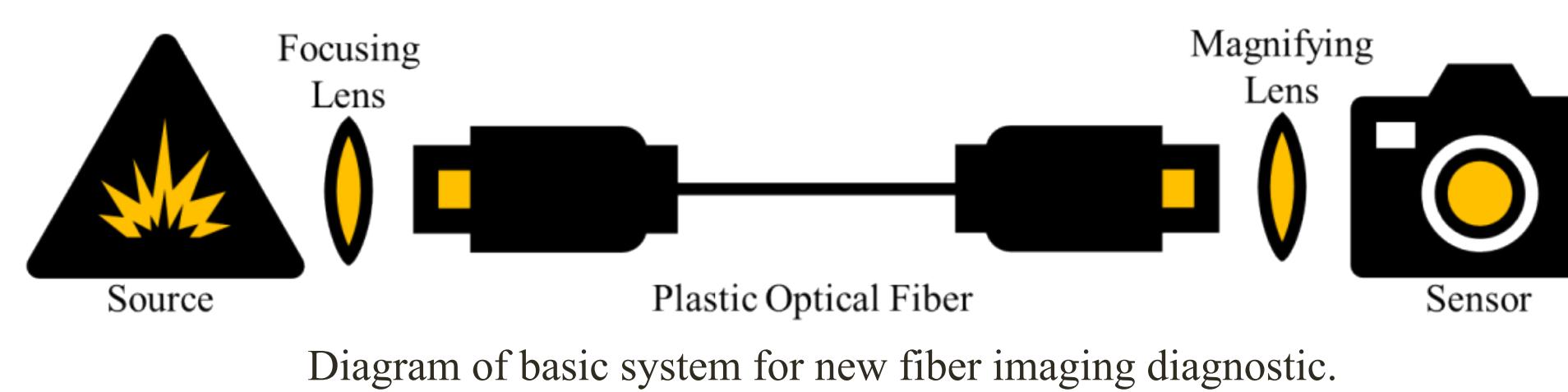
(a) Sandia National Laboratories, (b) University of New Mexico



Diagnostic Goals

- ❖ Versatile high resolution fiber imaging system
- ❖ Fast and easy installation
- ❖ Image multiple positions simultaneously

A compact and adaptable imaging system is presented as a technique to capture self-emission events in extreme environments. The concept was initiated as a tool for the Z machine; subsequently the project was named **Fiber Imaging on Z (FIZ)**. The FIZ design utilizes a commercial plastic optical fiber (POF) coupled between two lens configurations. A focusing lens forms an image onto the face of the transmitting POF. At the receiving end, a magnifying lens projects the transmission onto a gated sensor.



Imaging Goals for Pulsed Power

- ❖ Observe the formation of low-density plasmas that may contribute to current loss and impact instabilities in Z targets

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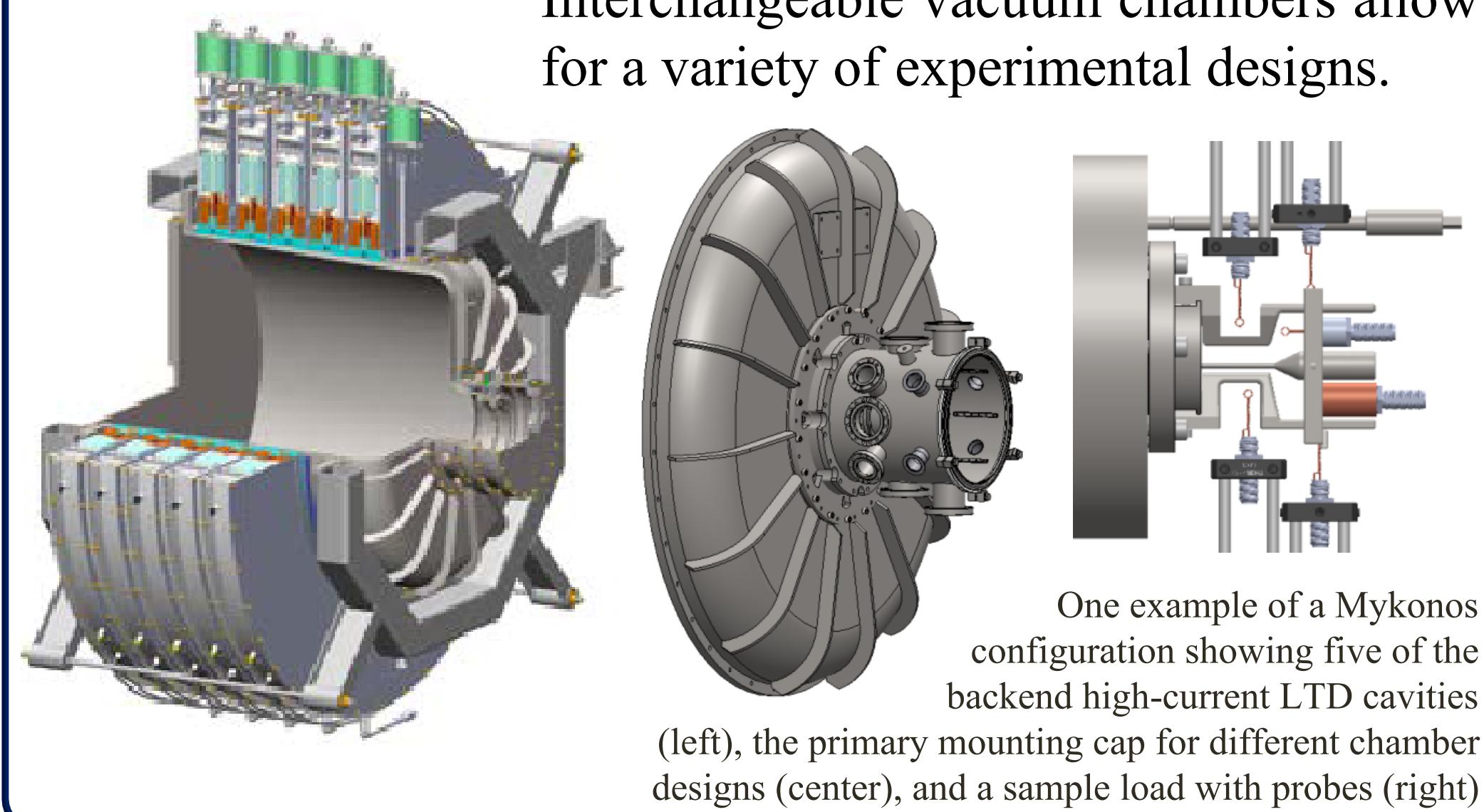
MagLIF on Z

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Interchangeable vacuum chambers allow for a variety of experimental designs.



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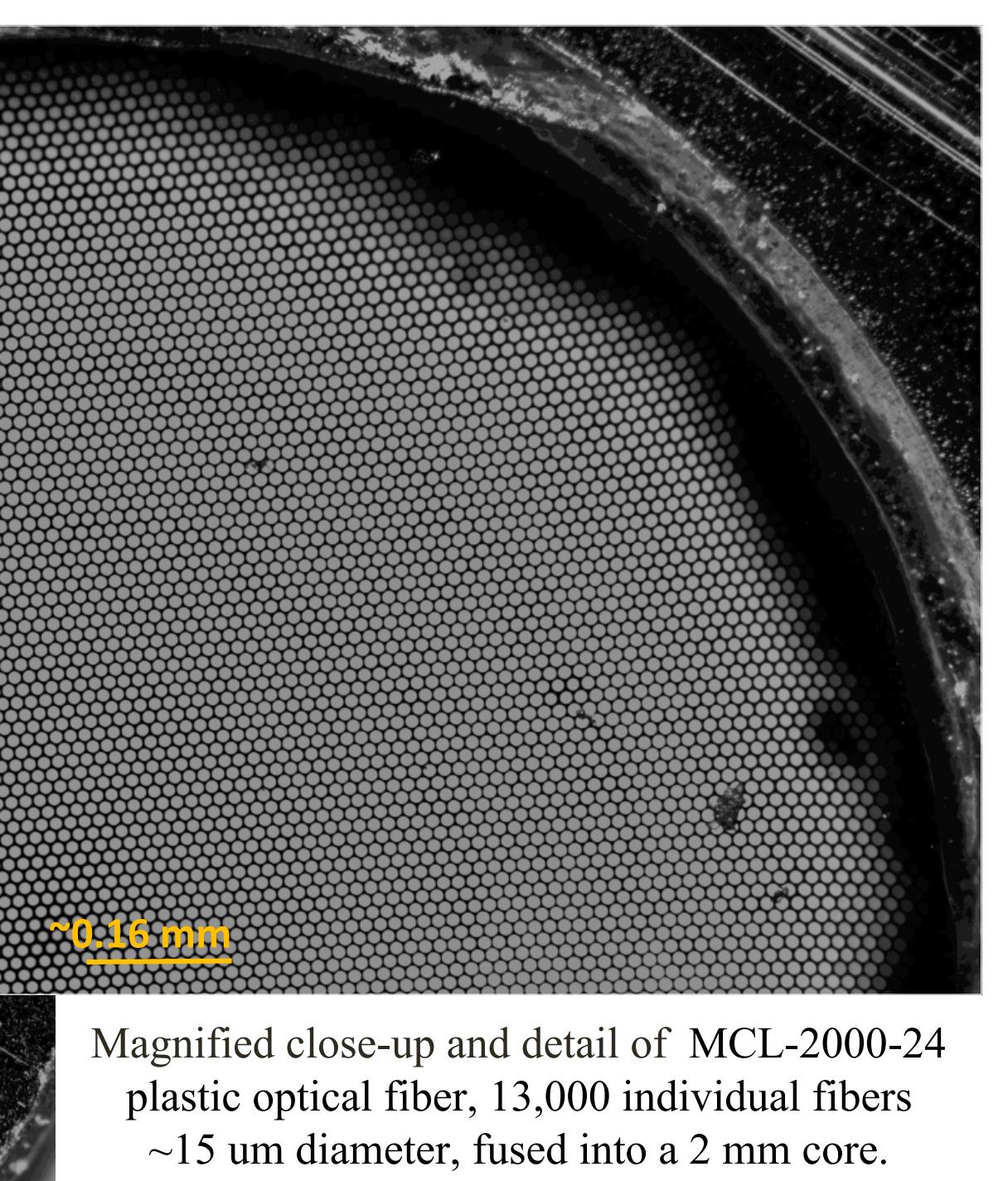
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FIZ Diagnostic Development

Plastic Optical Fiber

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- Jacket: polyethylene (PE)
- 13,000 individual fibers, each core ~15 micron in diameter
- 2 mm diameter fused core, 2.4 mm diameter with jacket
- Step-index multimode
- Transmission rate
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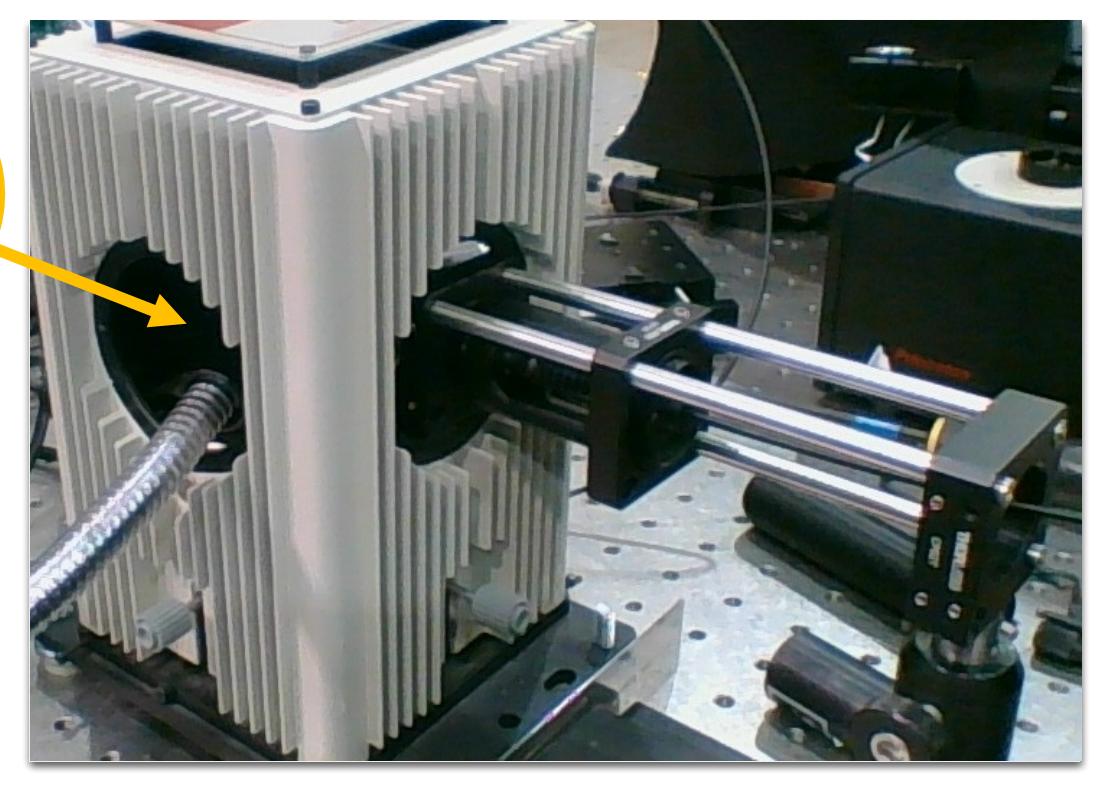


Magnified close-up and detail of MCL-2000-24 plastic optical fiber, 13,000 individual fibers ~15 μm diameter, fused into a 2 mm core.

Source Side

- ❖ Input sources

- Arc lamp, Xenon
 - 9 μs FWHM
 - 800 mJ
- LED with 1951 USAF resolution target

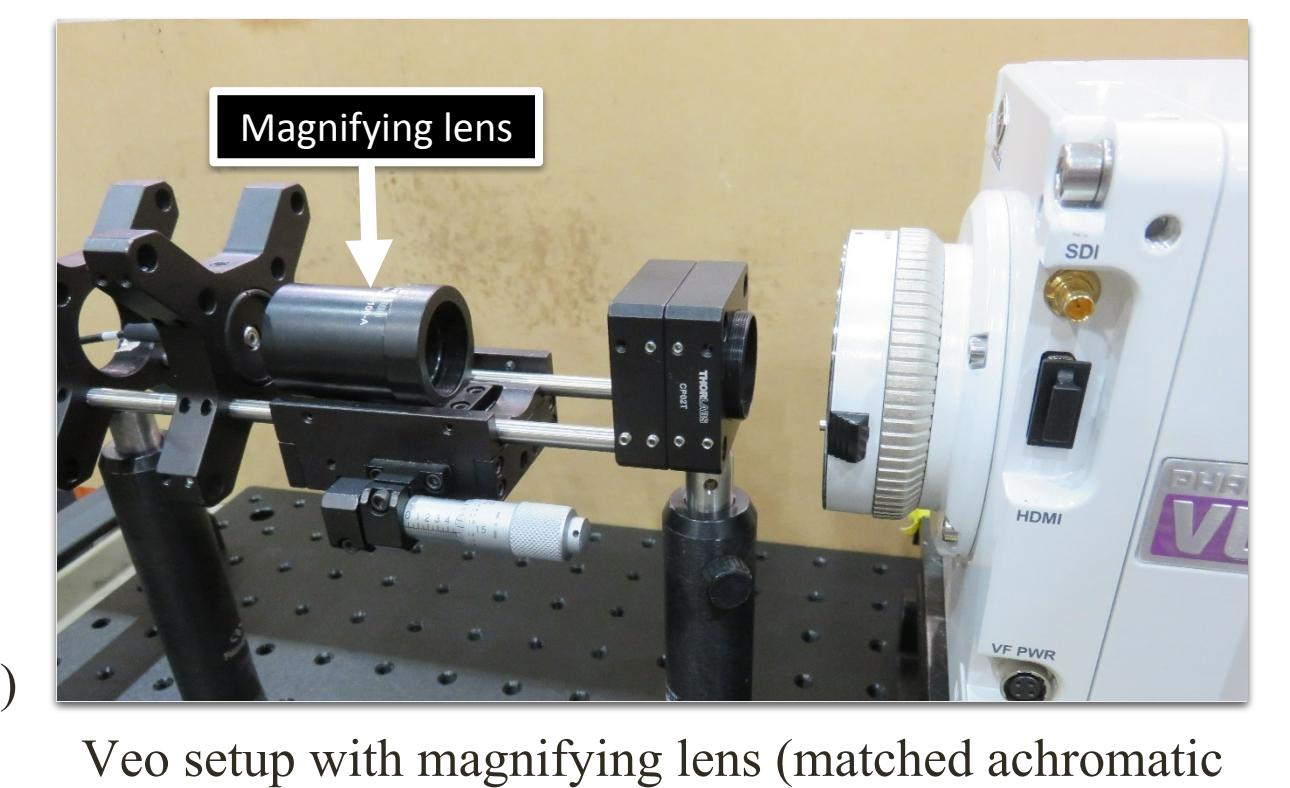


Arc lamp with focusing lens cage system. Detail of interior electrodes.

Sensor Side

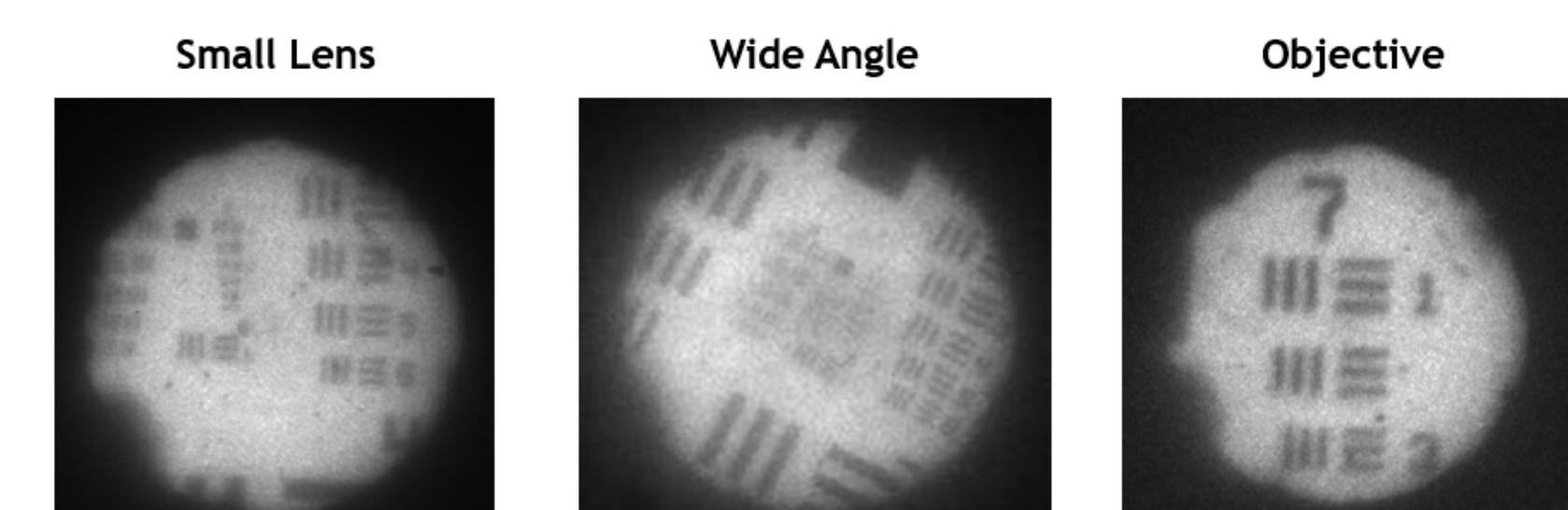
- ❖ Focusing lenses

- Small diameter, < 10 mm
- Objective, 20x
- Wide angle, 67° FOV

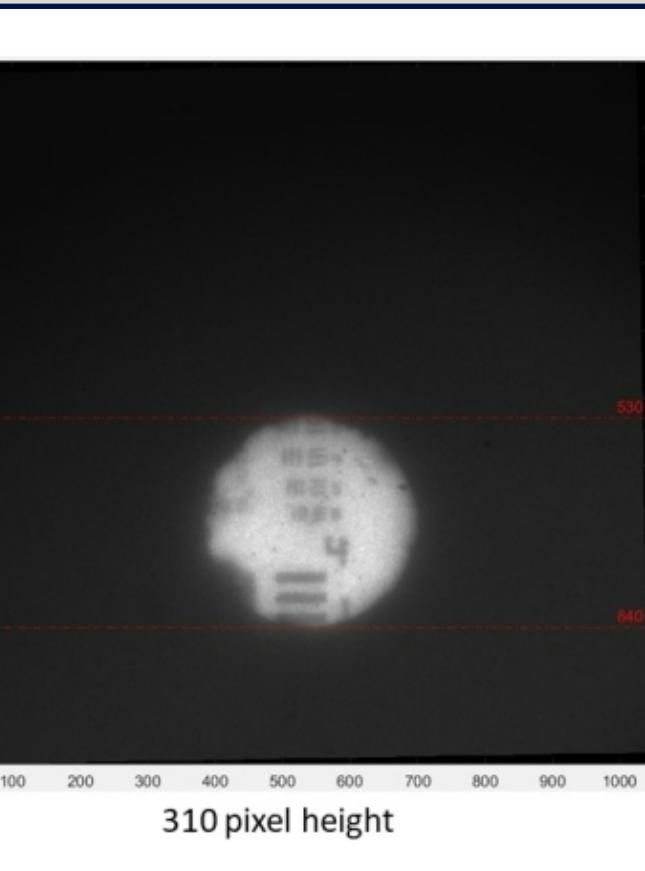
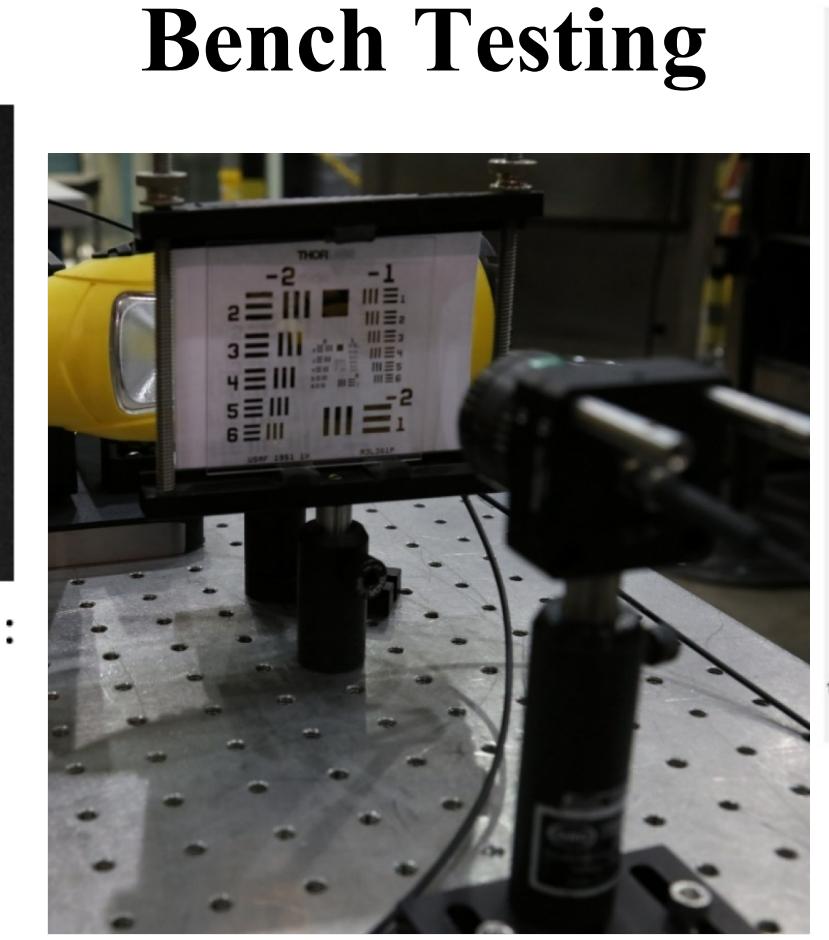


Veo setup with magnifying lens (matched achromatic doublet pair) imaging directly to the sensor.

Bench Testing



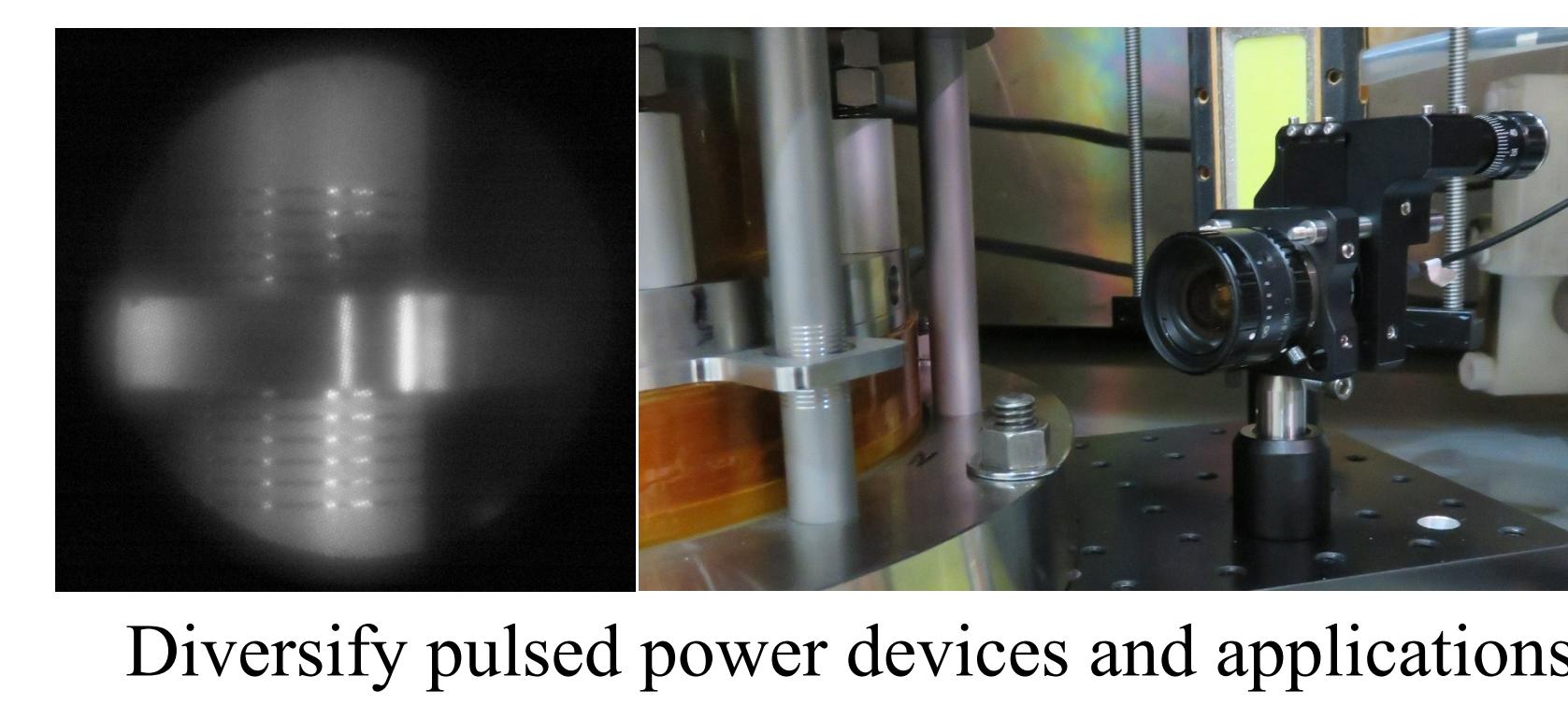
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FOV calculation based on USAF resolution target

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 - Laser cutting shows promise to cut and polish simultaneously (more work is needed)
 - Custom inspection tool built to see the full face of the 2 mm fiber with 10x magnification
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Potential Advancements



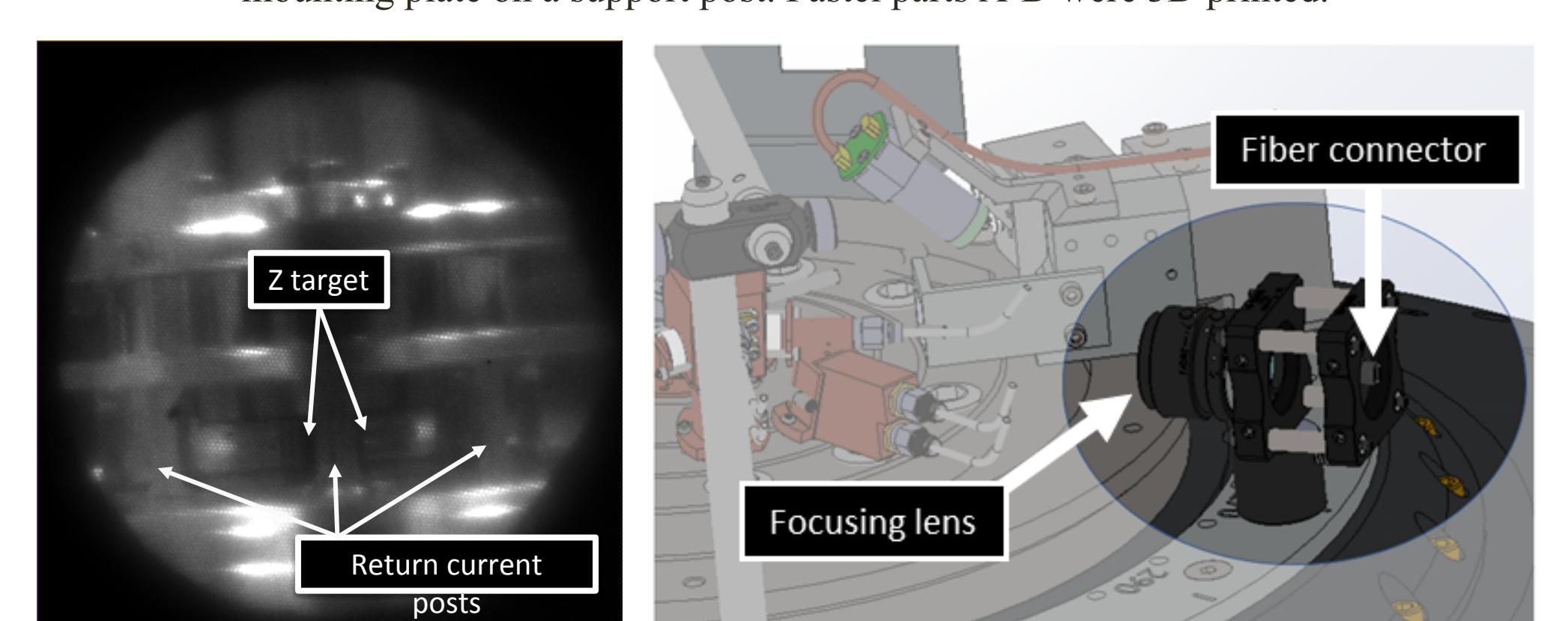
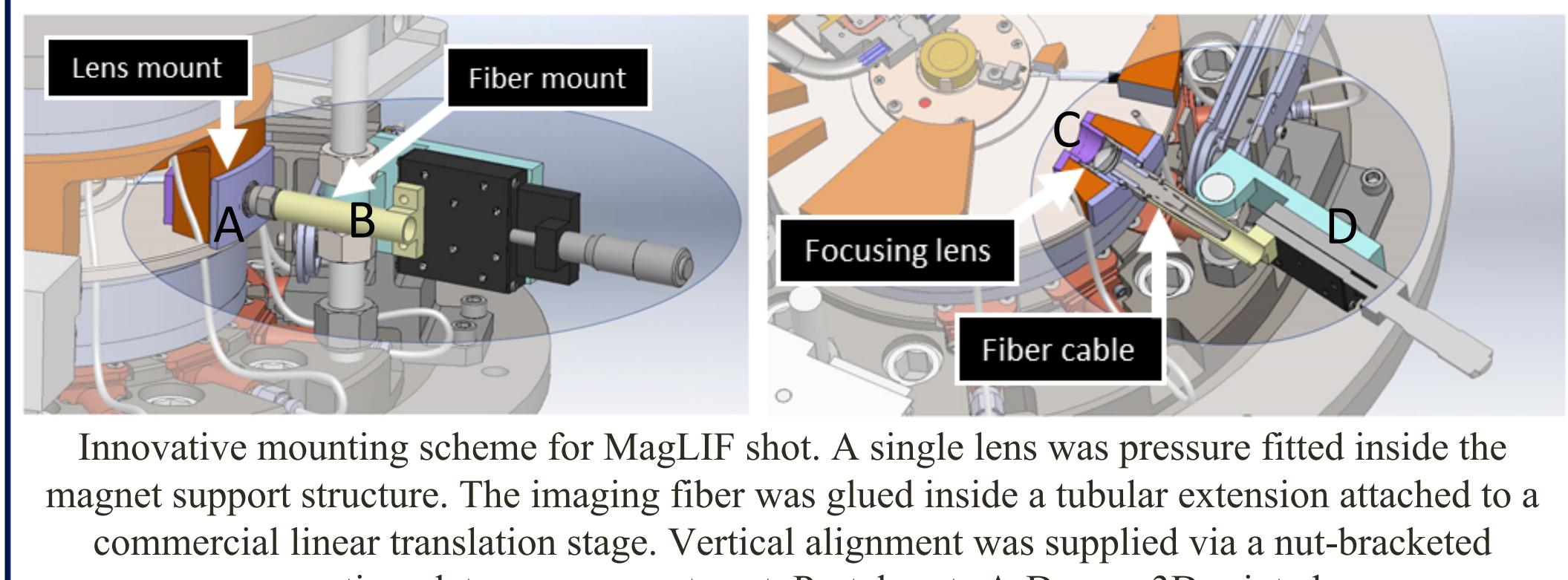
Diversify pulsed power devices and applications
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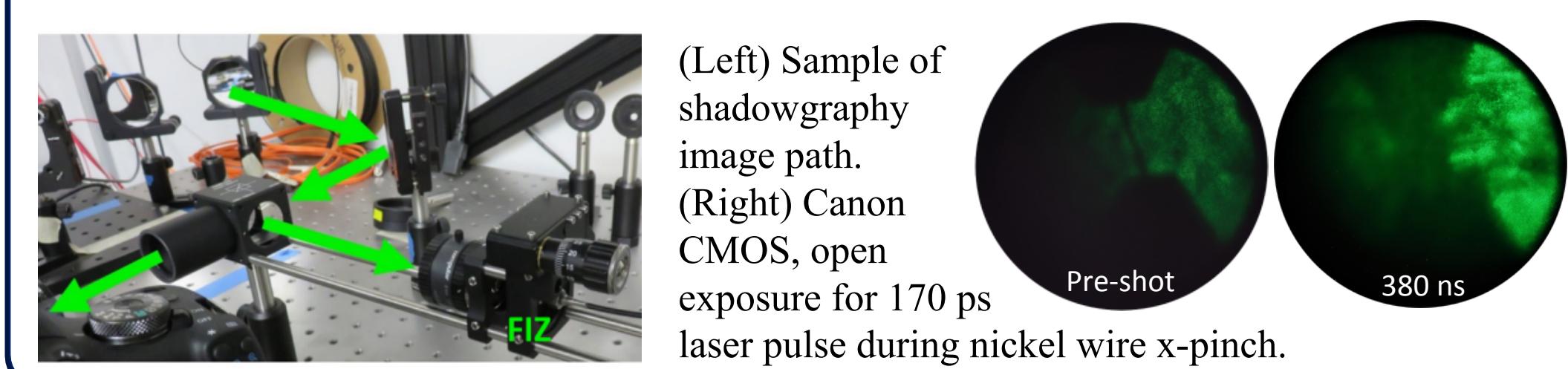
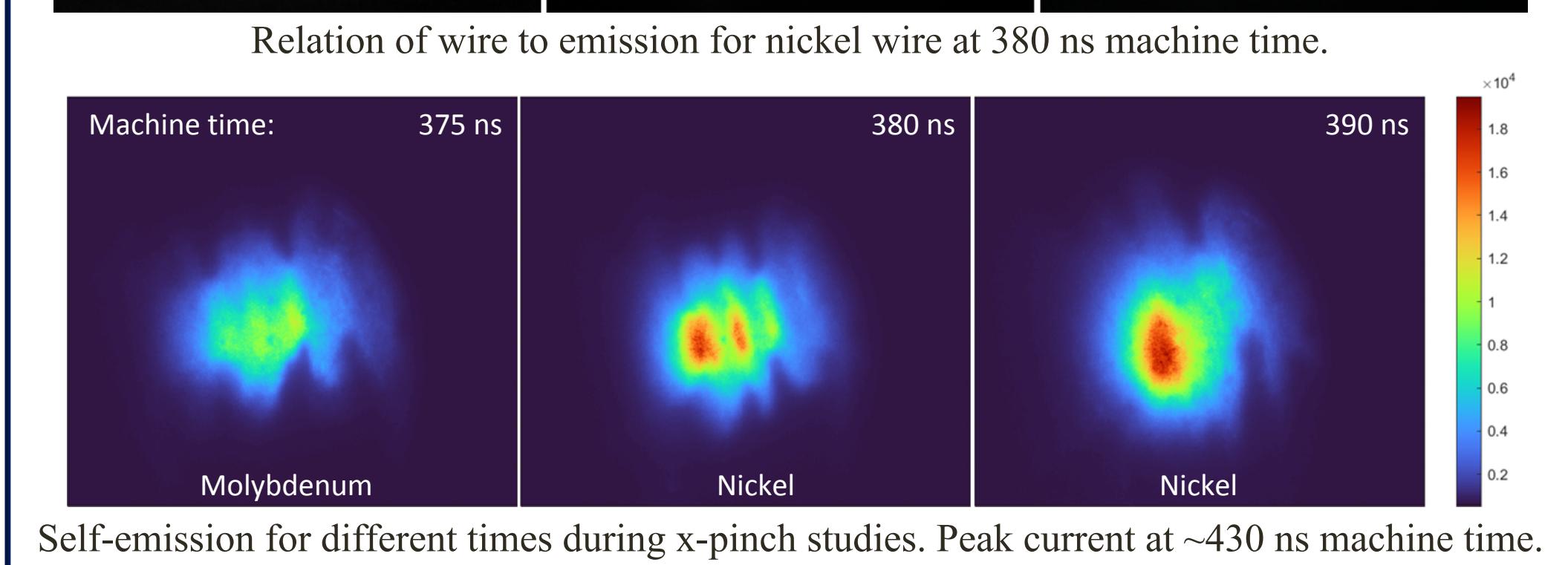
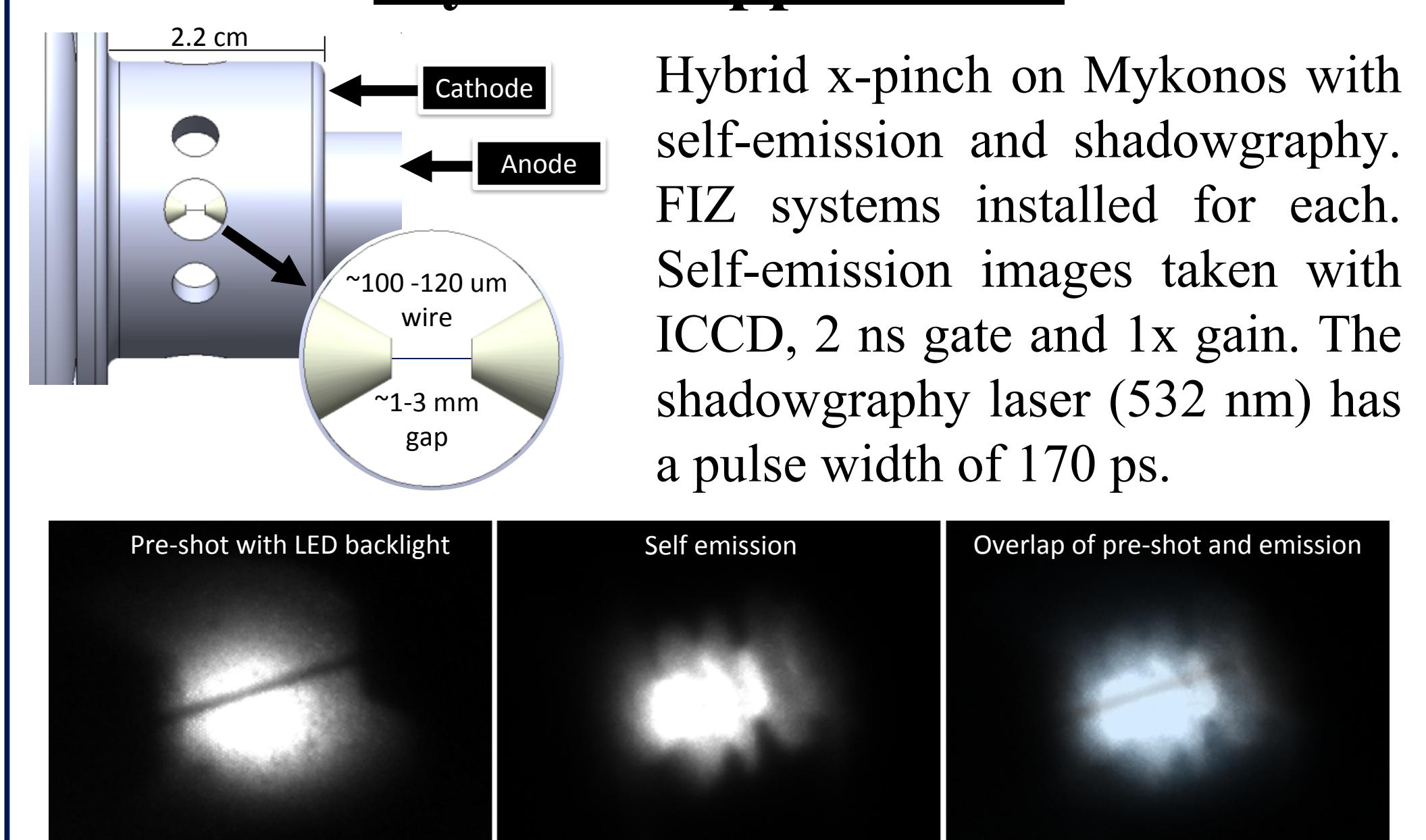
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FOV test image with commercial lens configuration on the aperture ring.
Image taken prior to installation on Z for MagLIF shot.

Mykonos Applications

Hybrid x-pinch on Mykonos with self-emission and shadowgraphy. FIZ systems installed for each. Self-emission images taken with ICCD, 2 ns gate and 1x gain. The shadowgraphy laser (532 nm) has a pulse width of 170 ps.



(Left) Sample of shadowgraphy image path.
(Right) Canon CMOS, open exposure for 170 ps laser pulse during nickel wire x-pinch.



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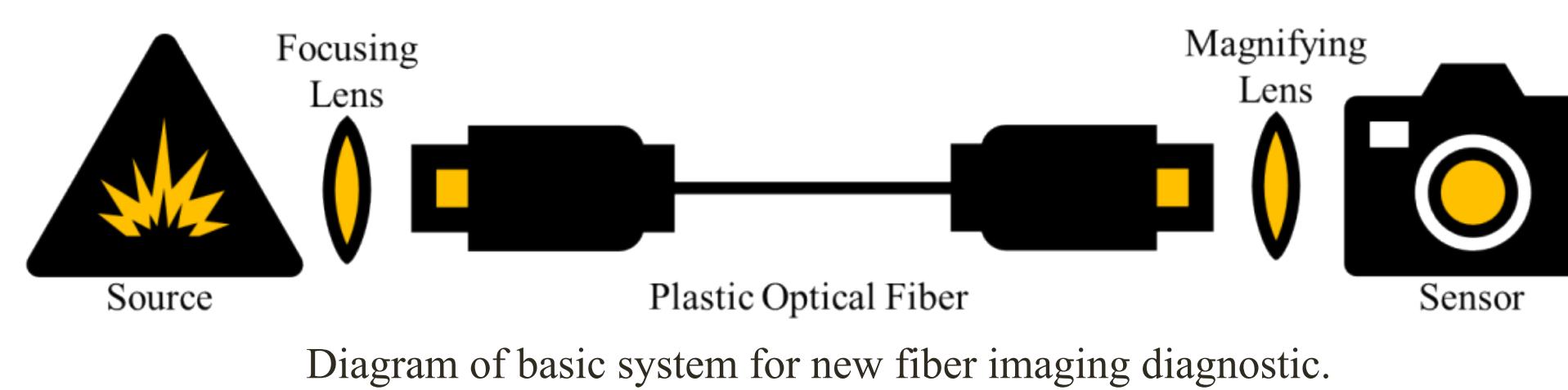
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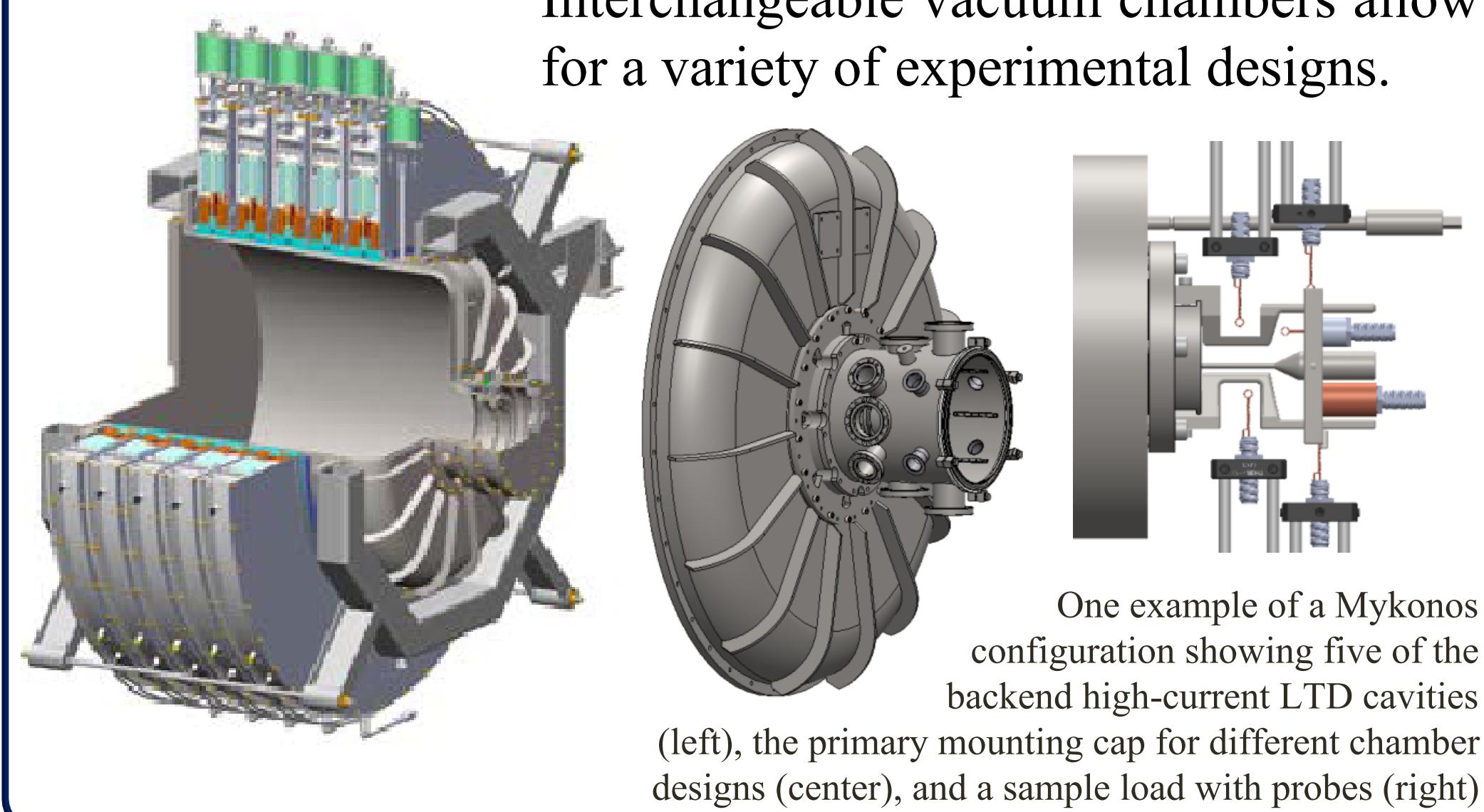
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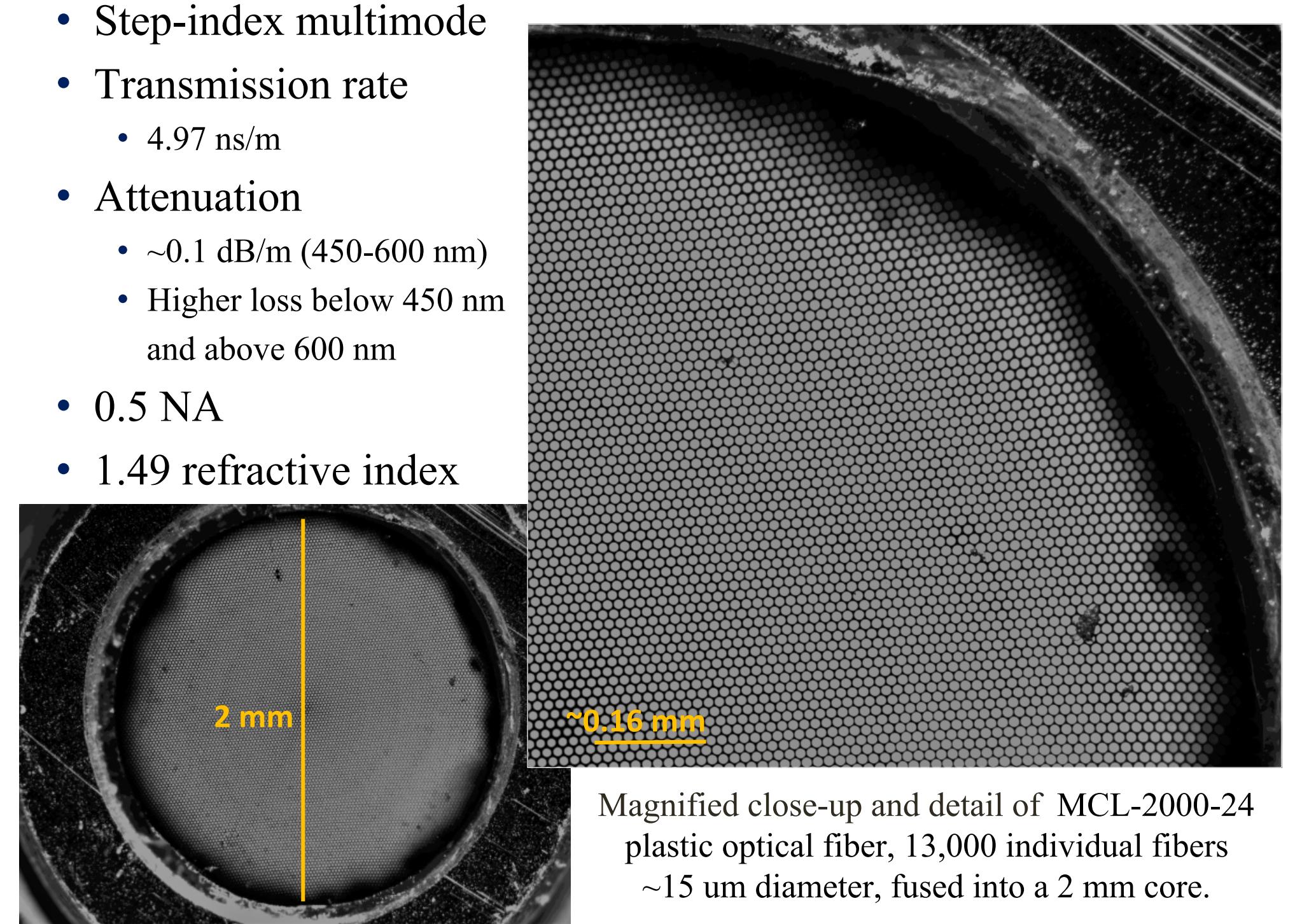
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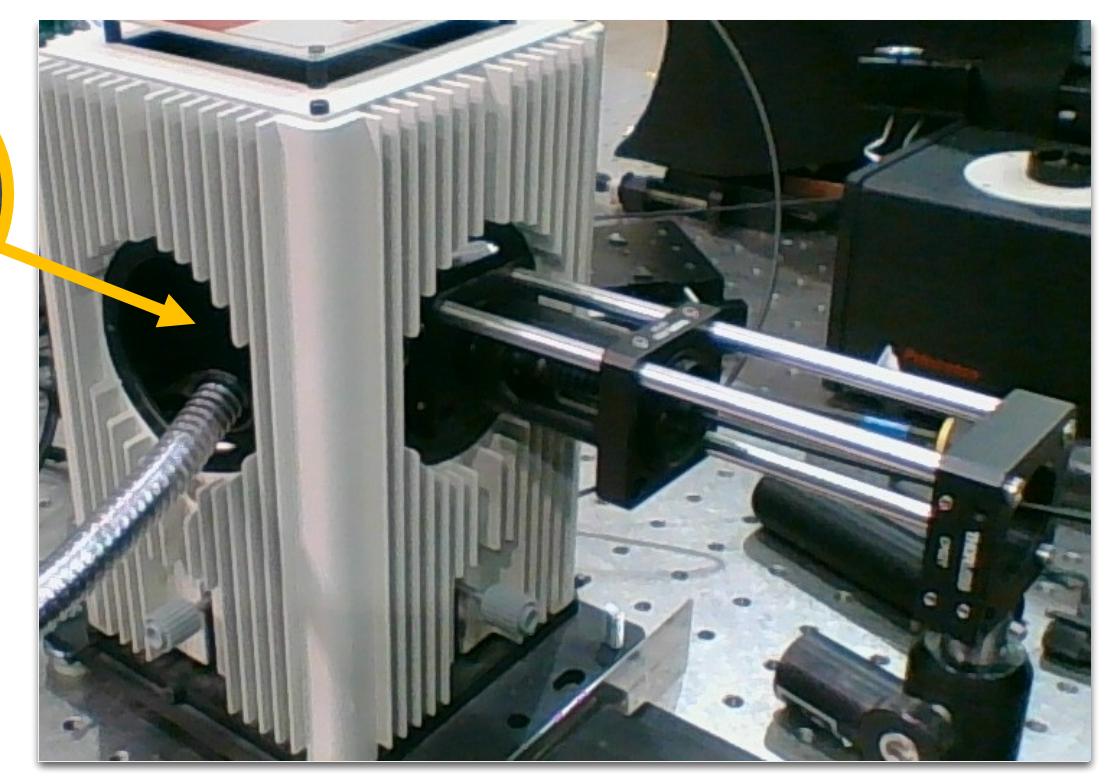


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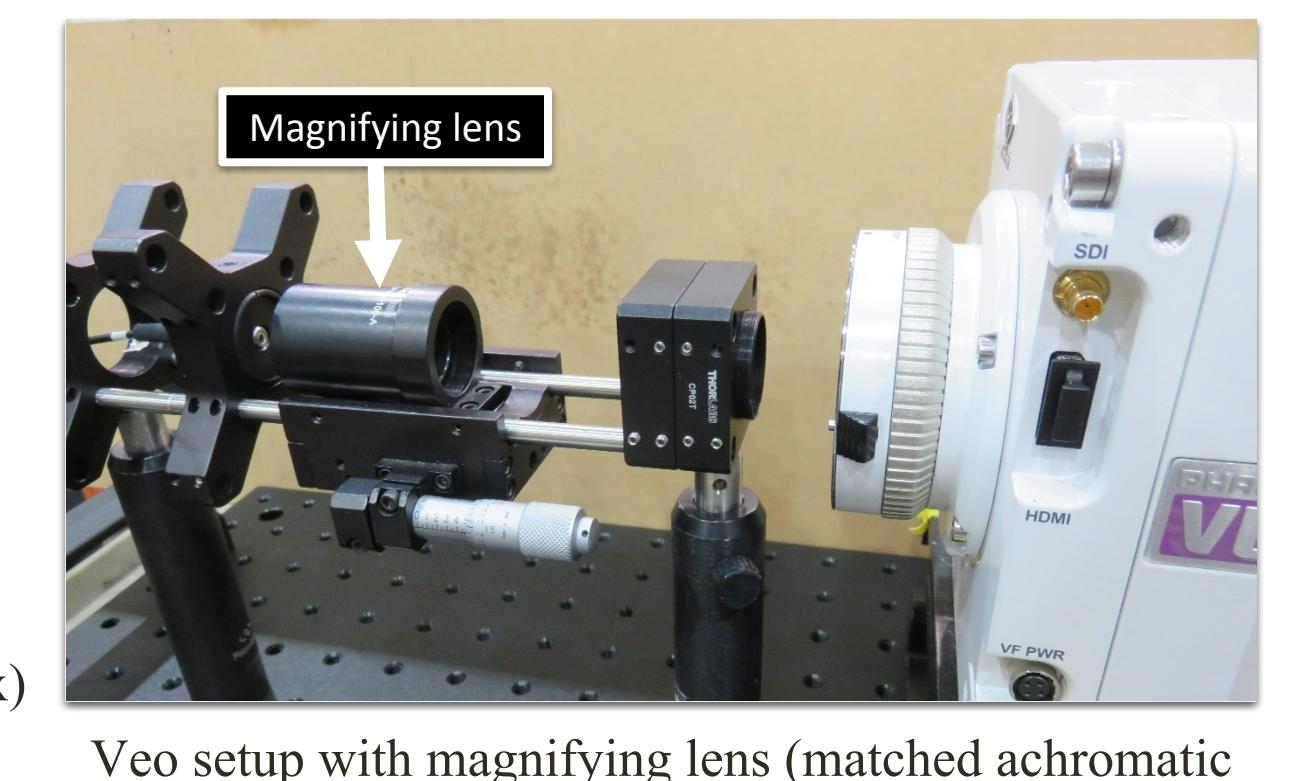


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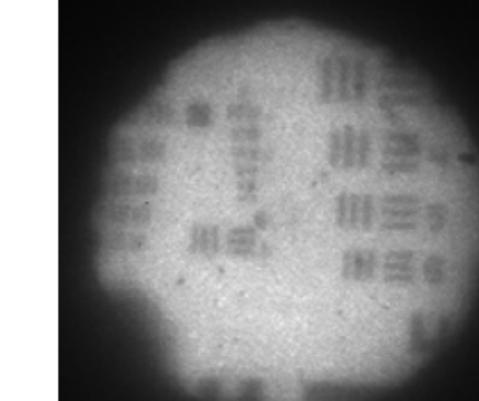
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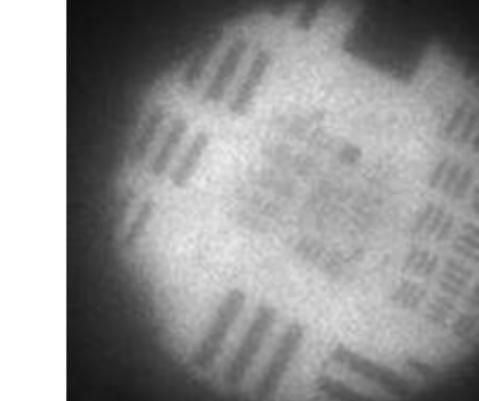
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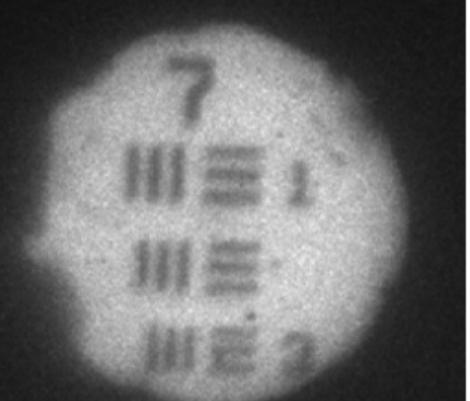
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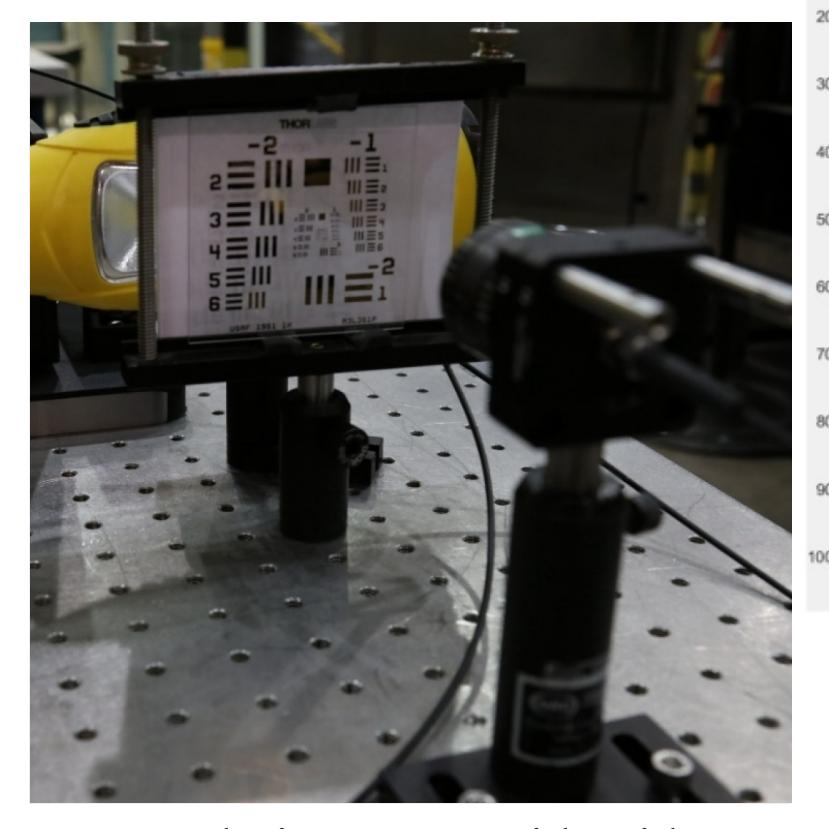


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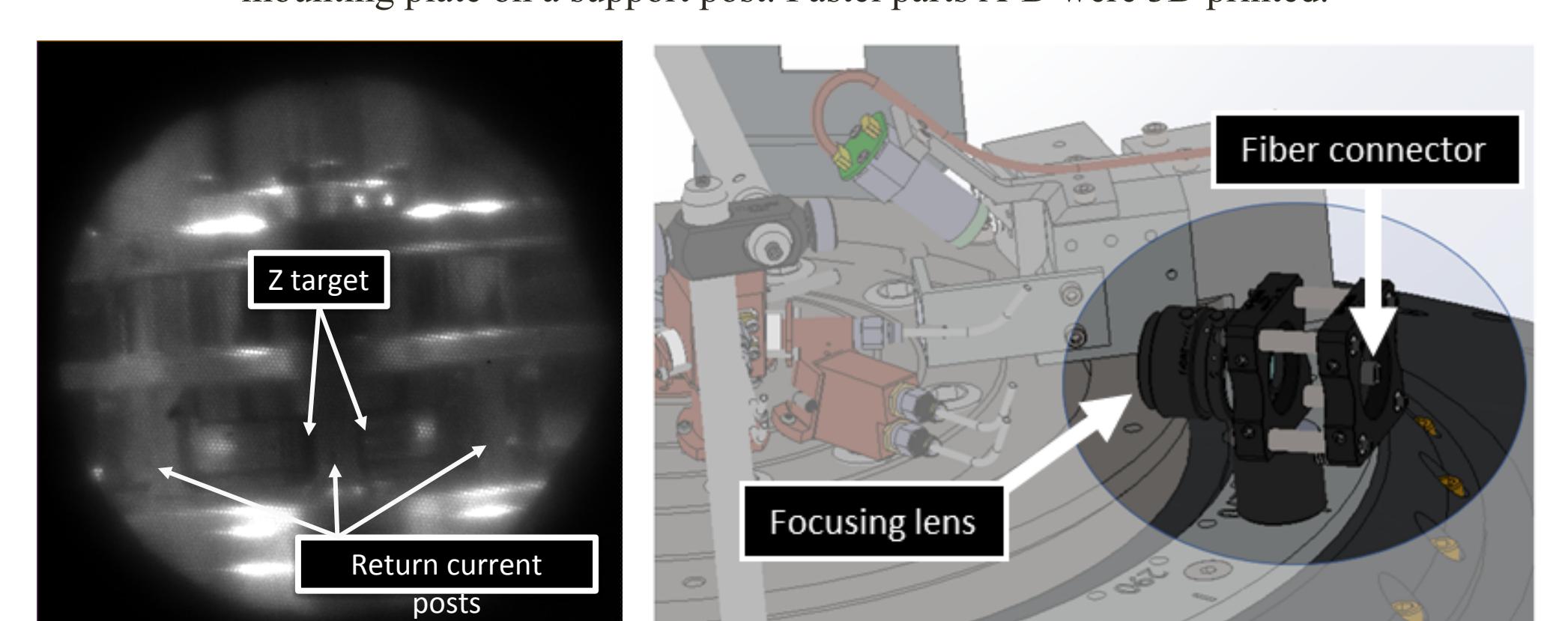
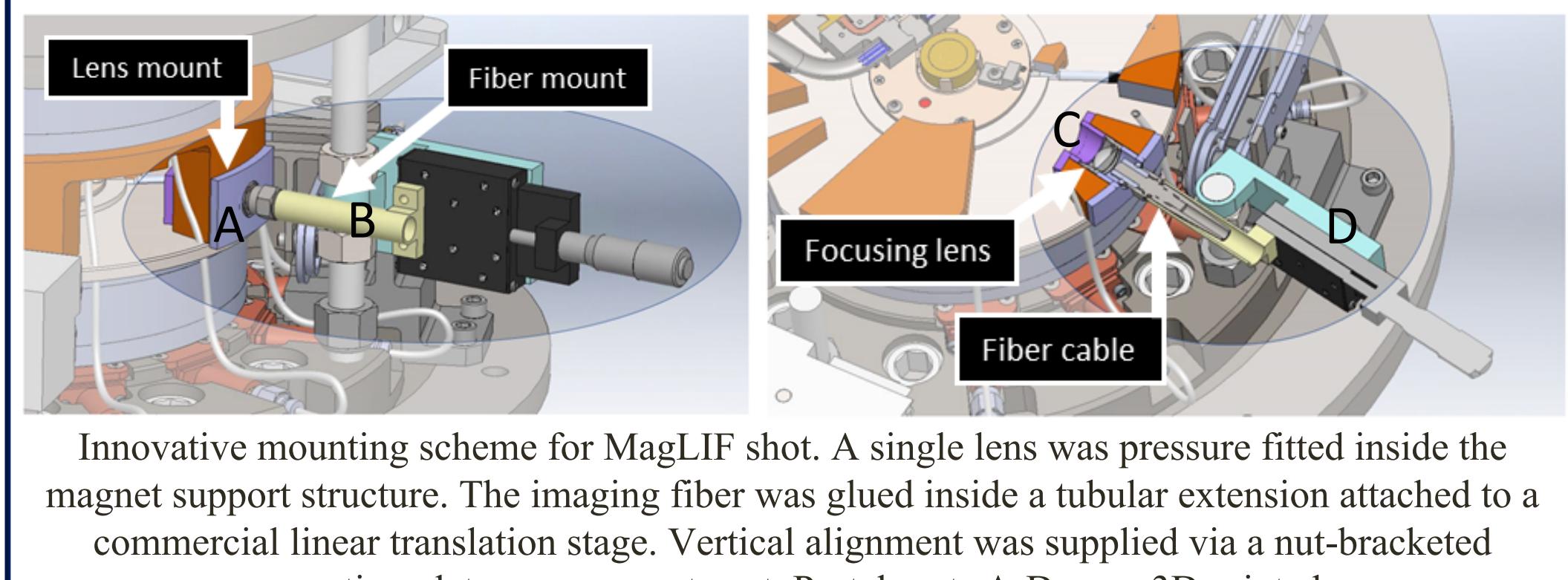
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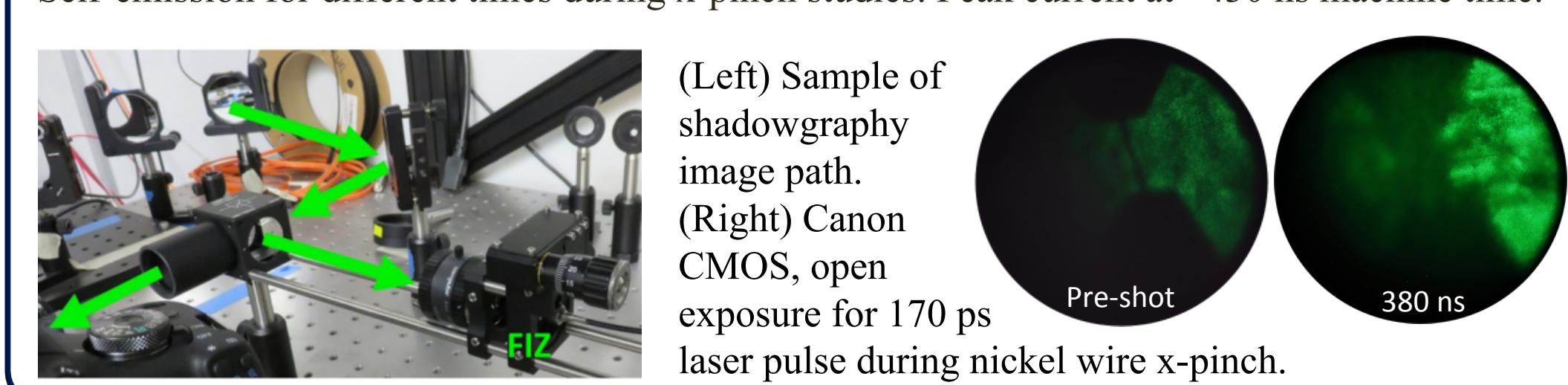
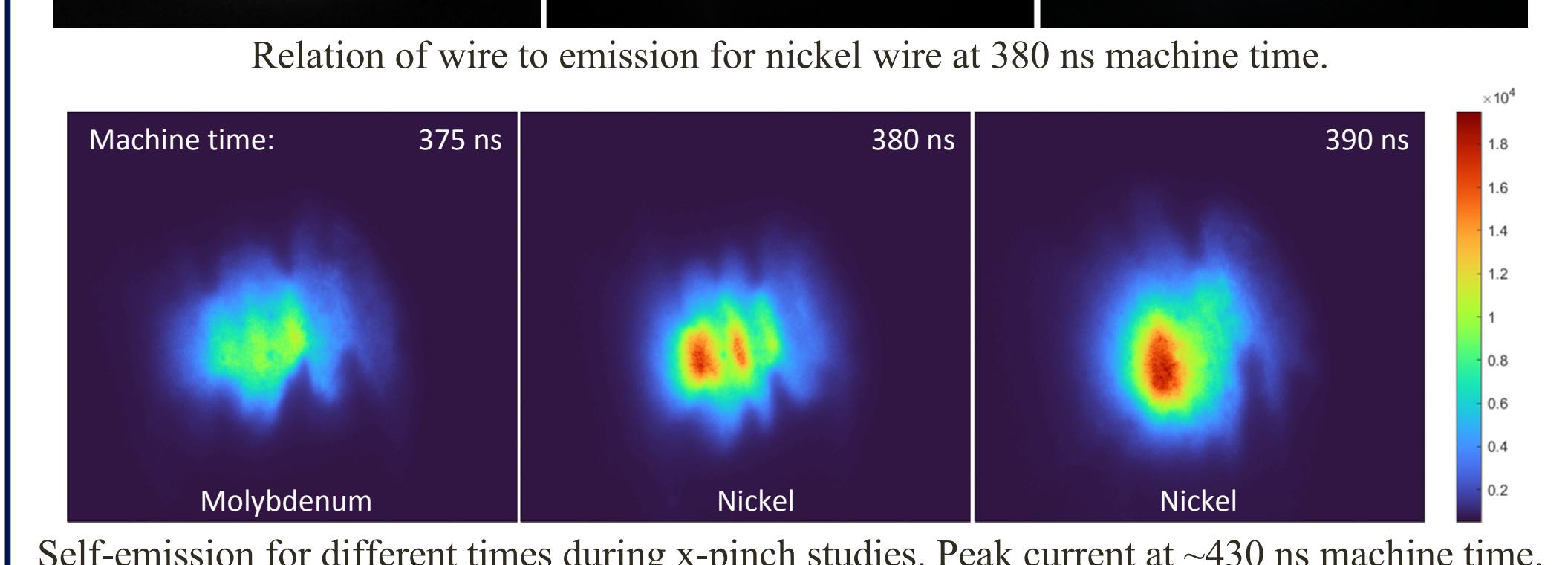
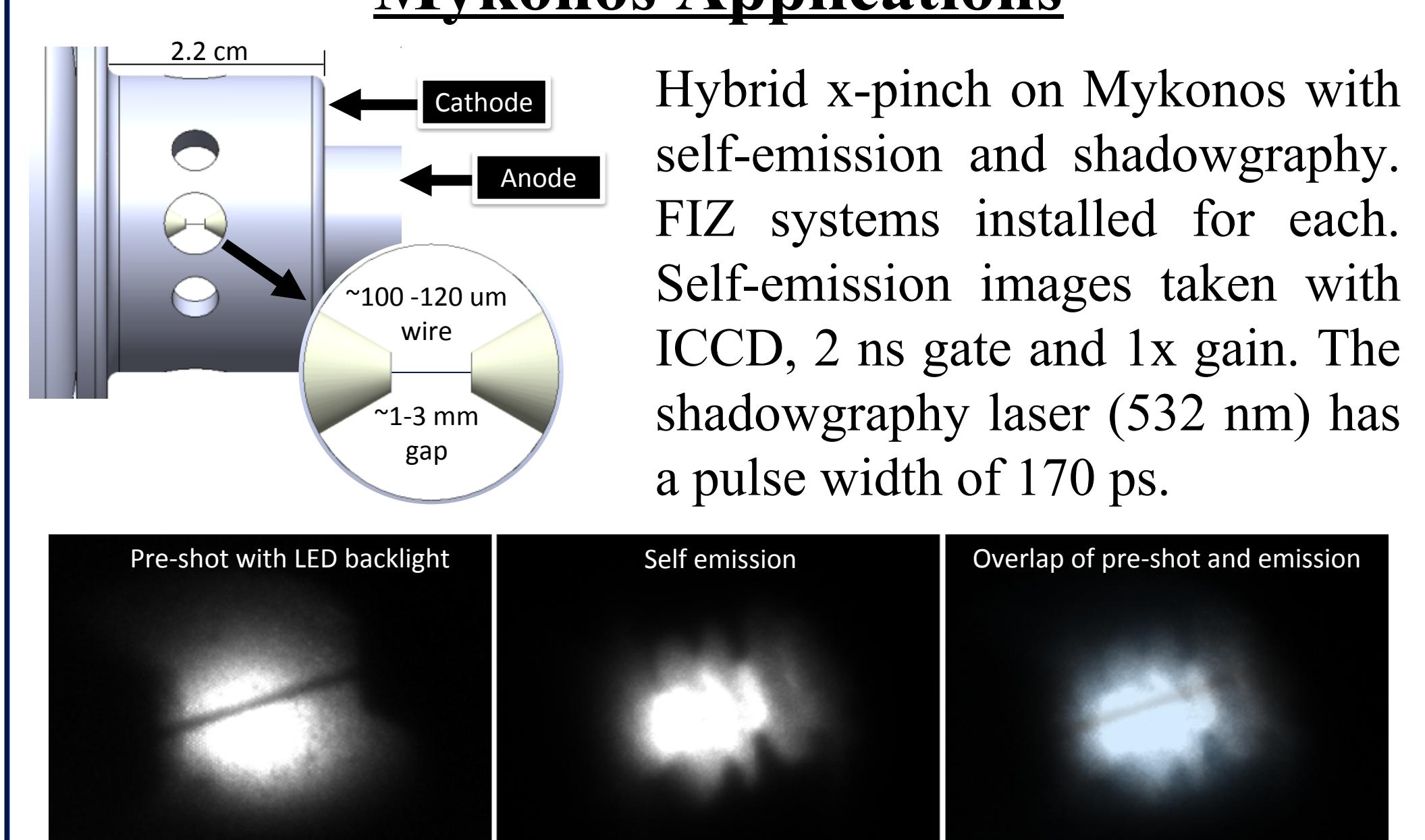


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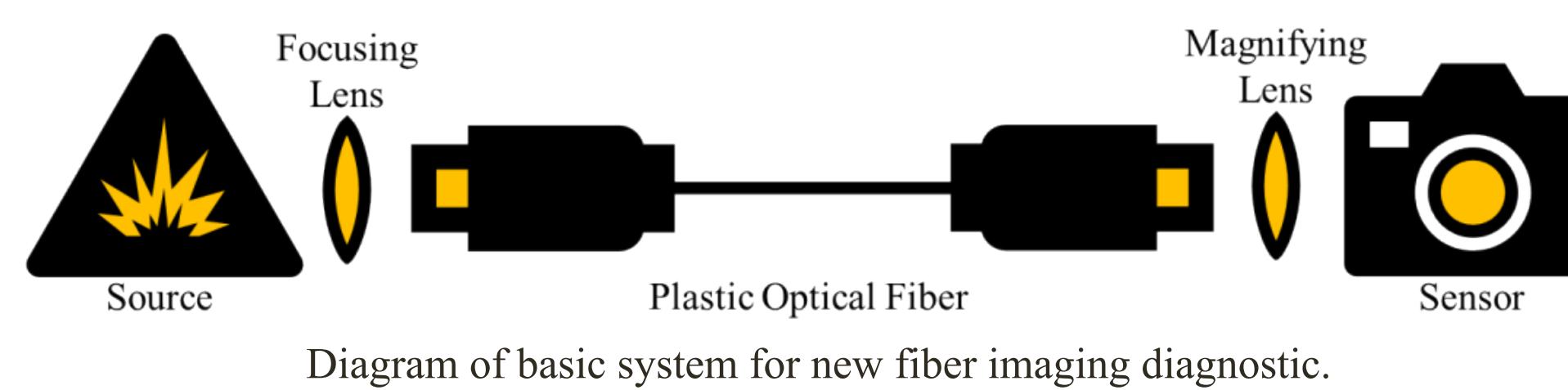
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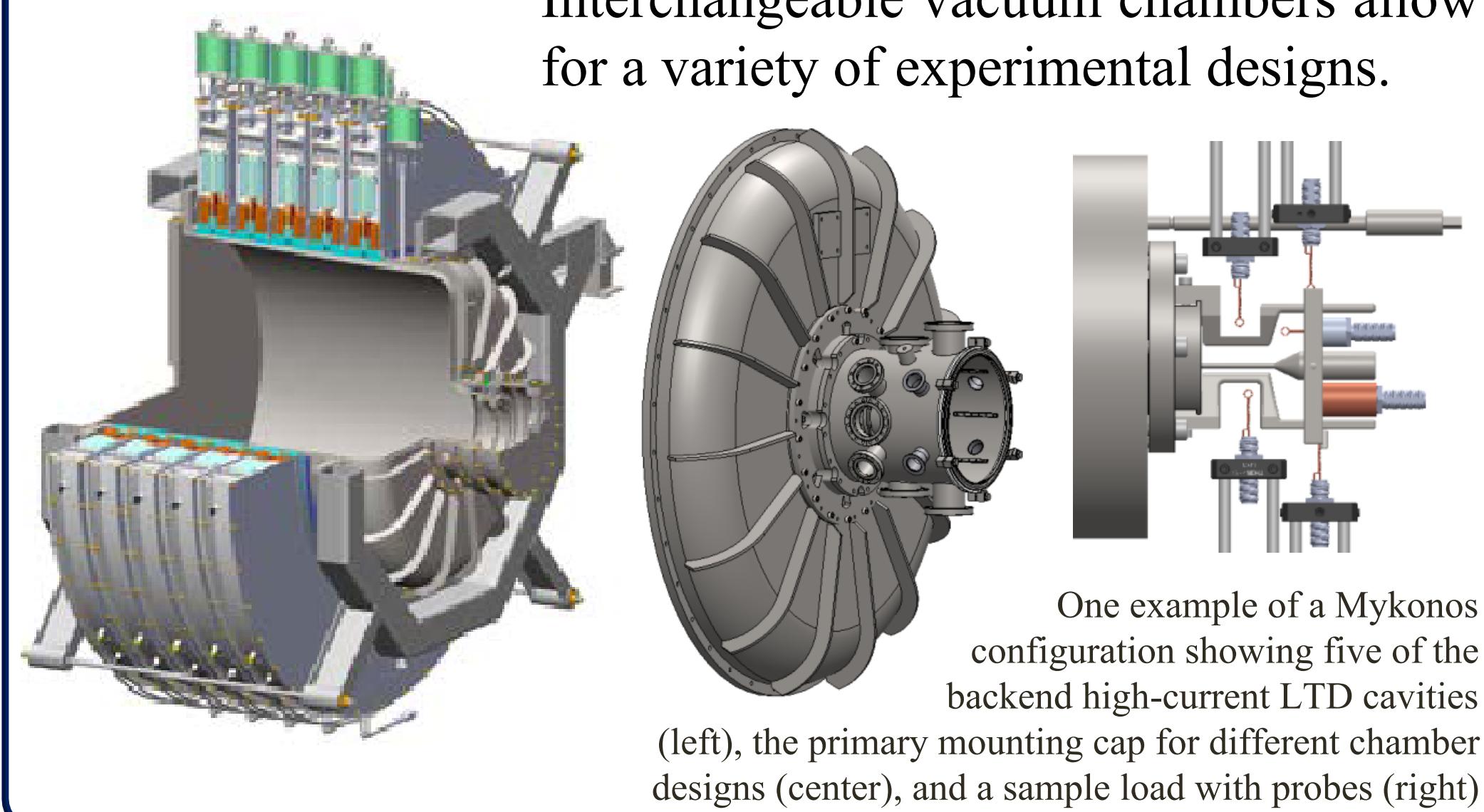
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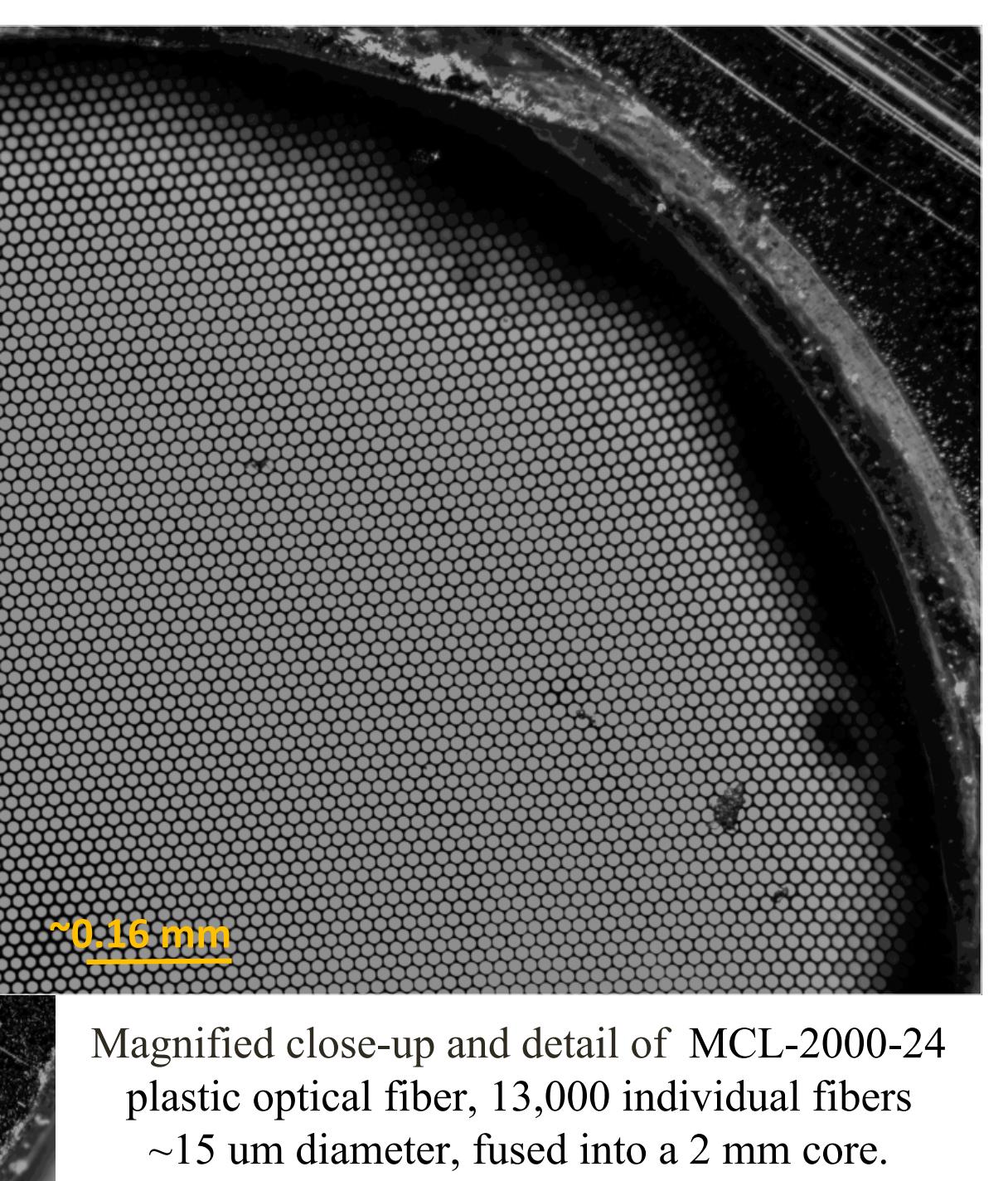
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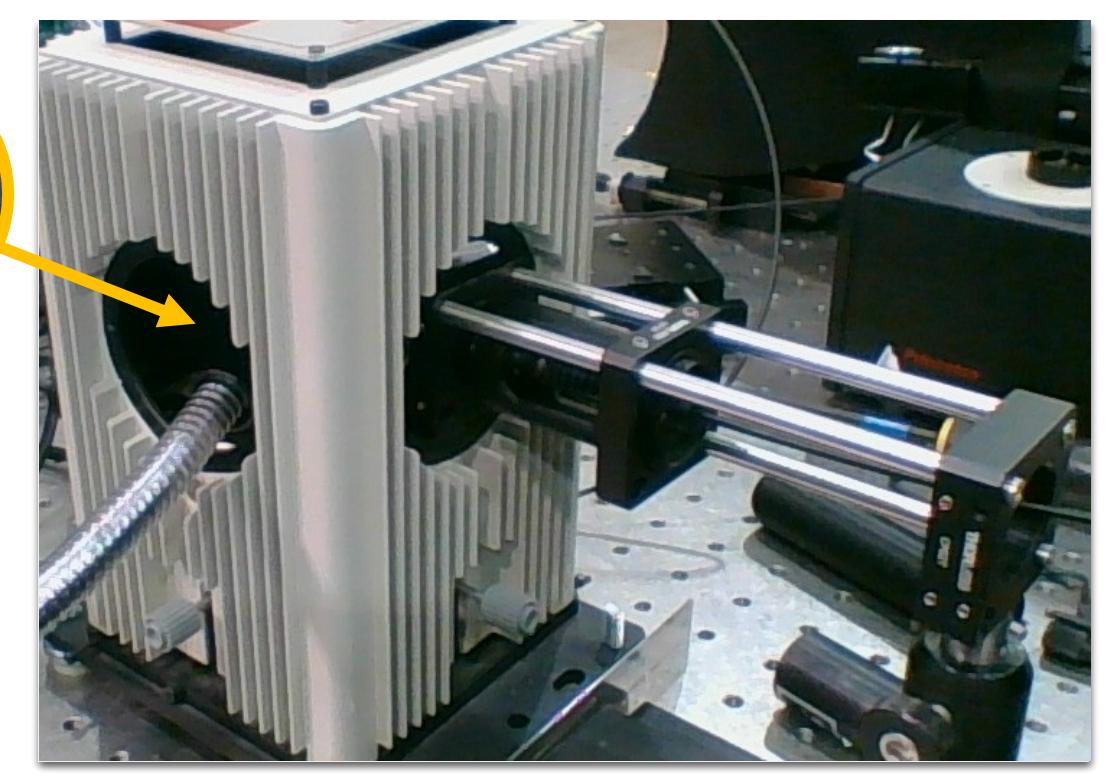


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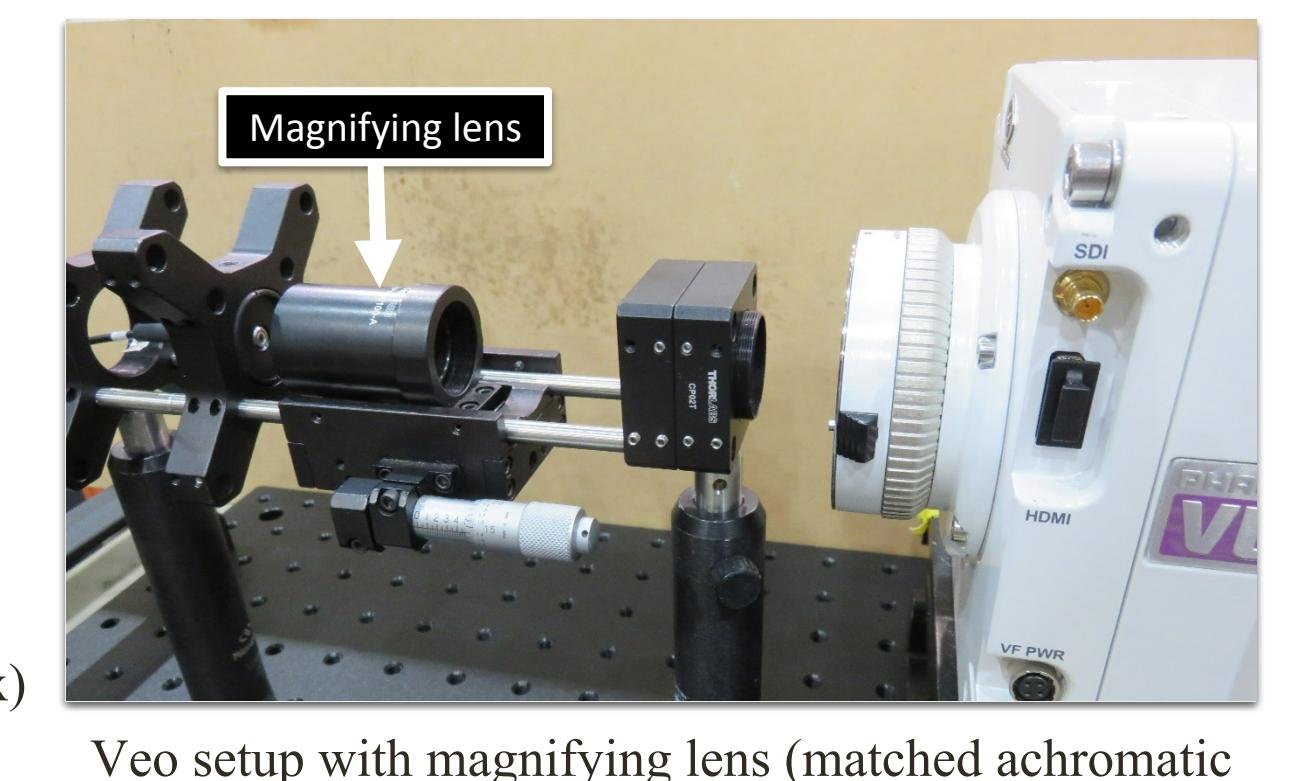


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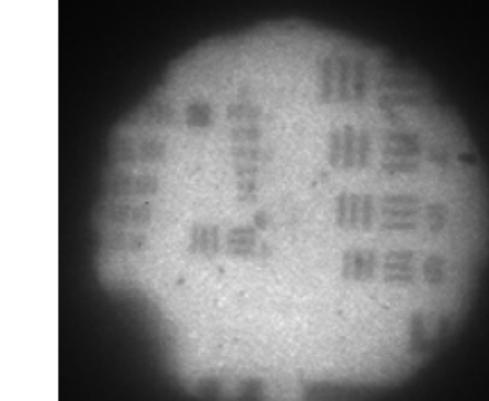
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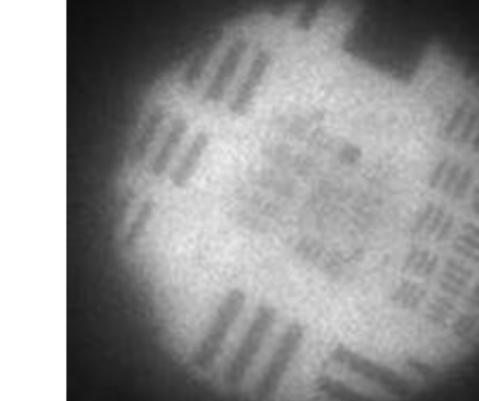
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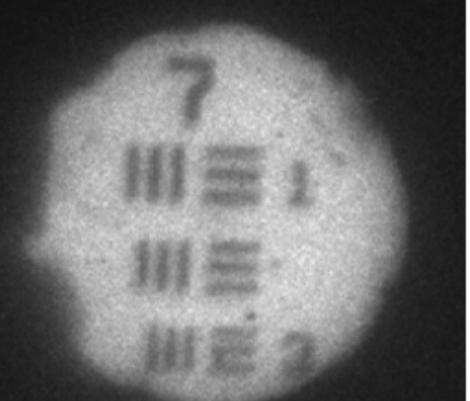
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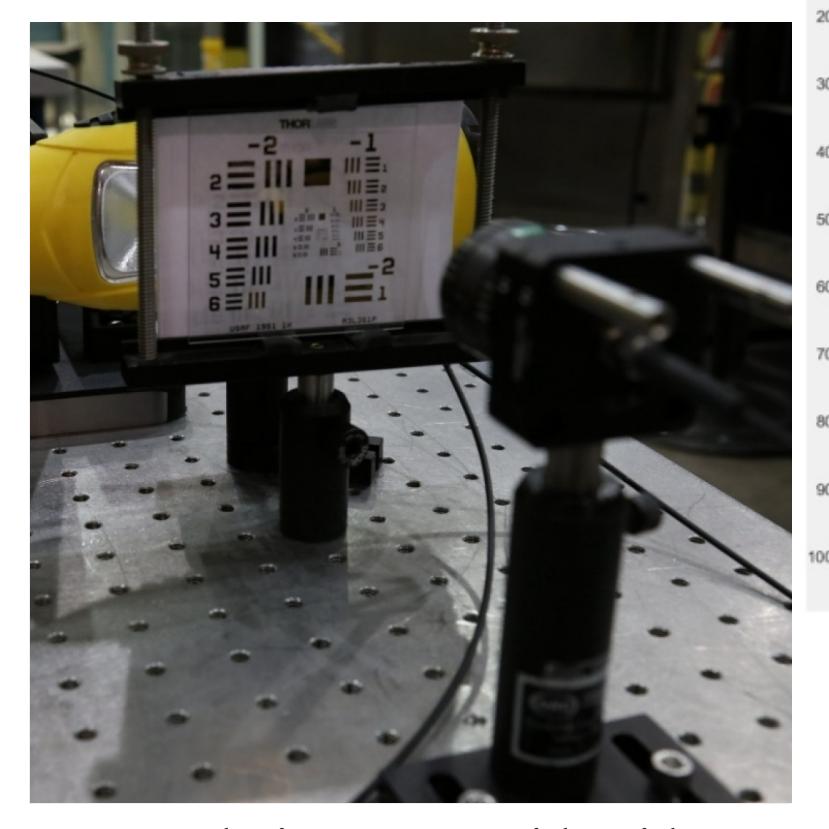


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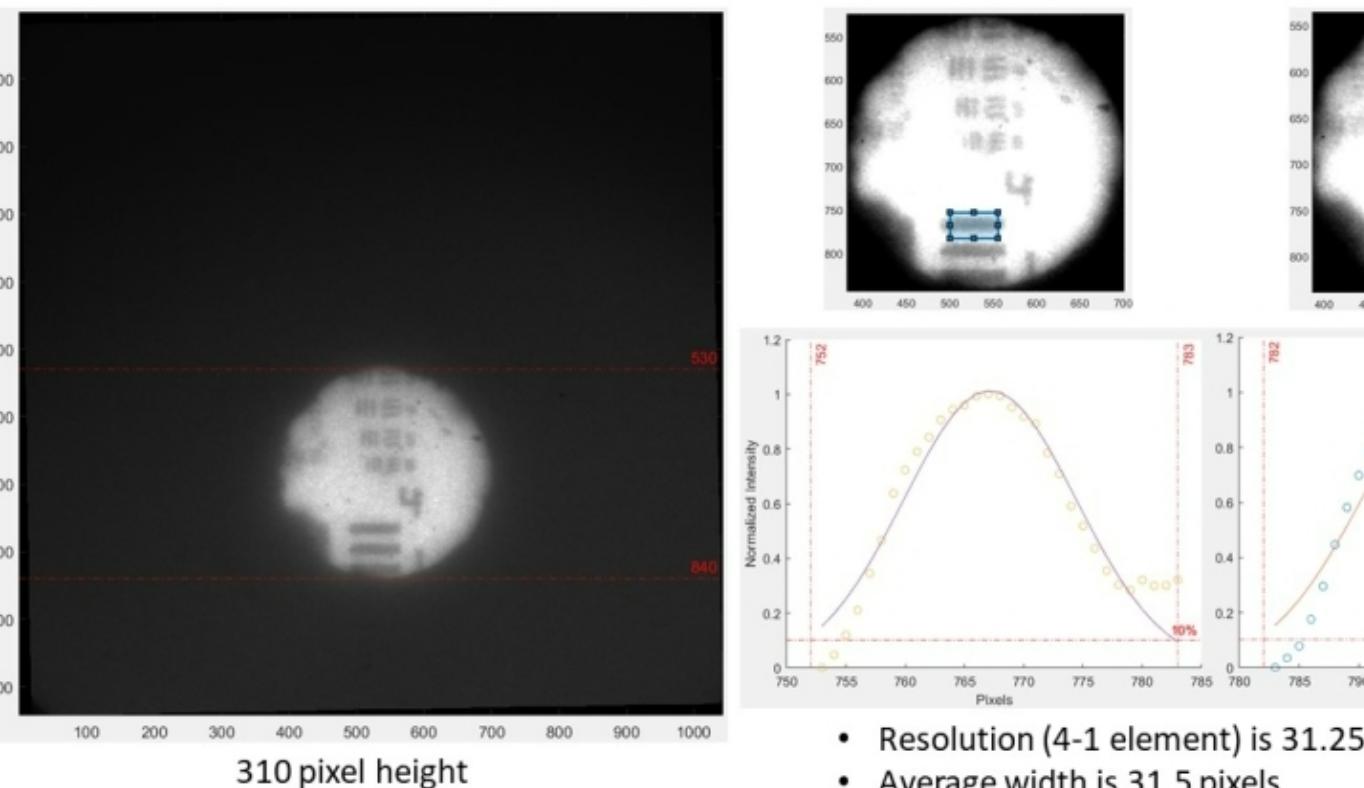


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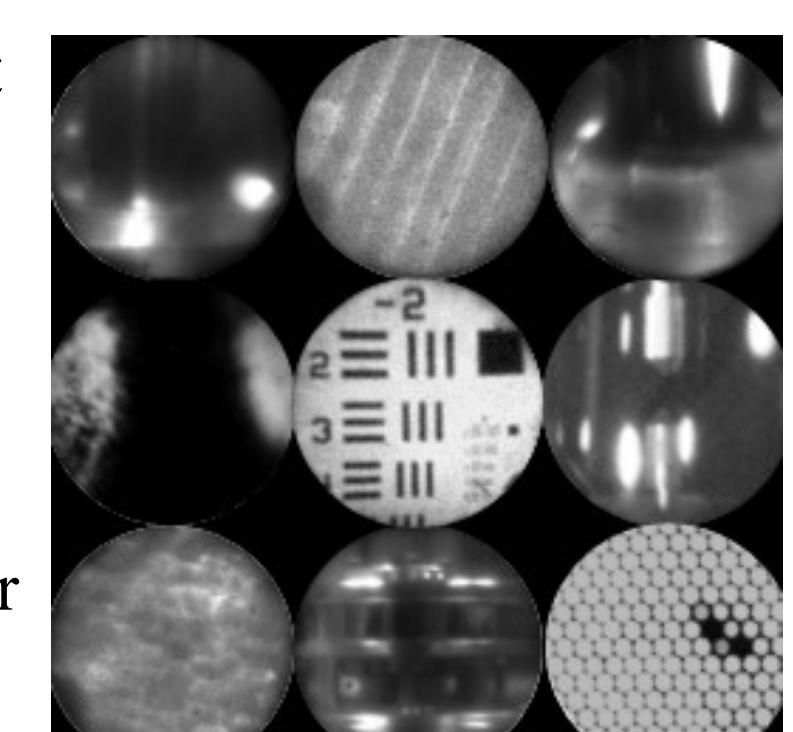
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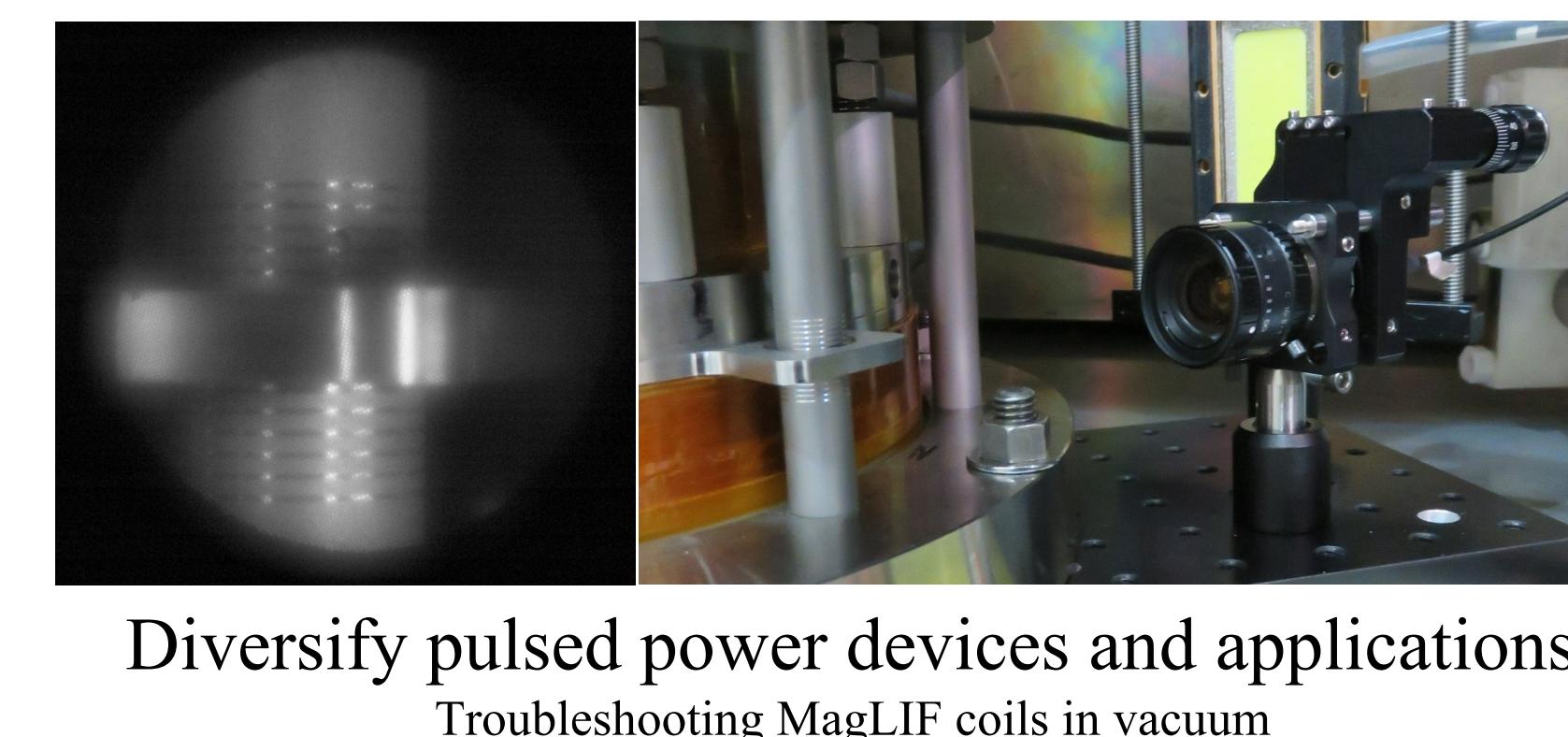
Build different fiber arrays to:

- Maximize the sensor
- Vary time and views
- Illuminate, filter and image in parallel
- Increase FOV



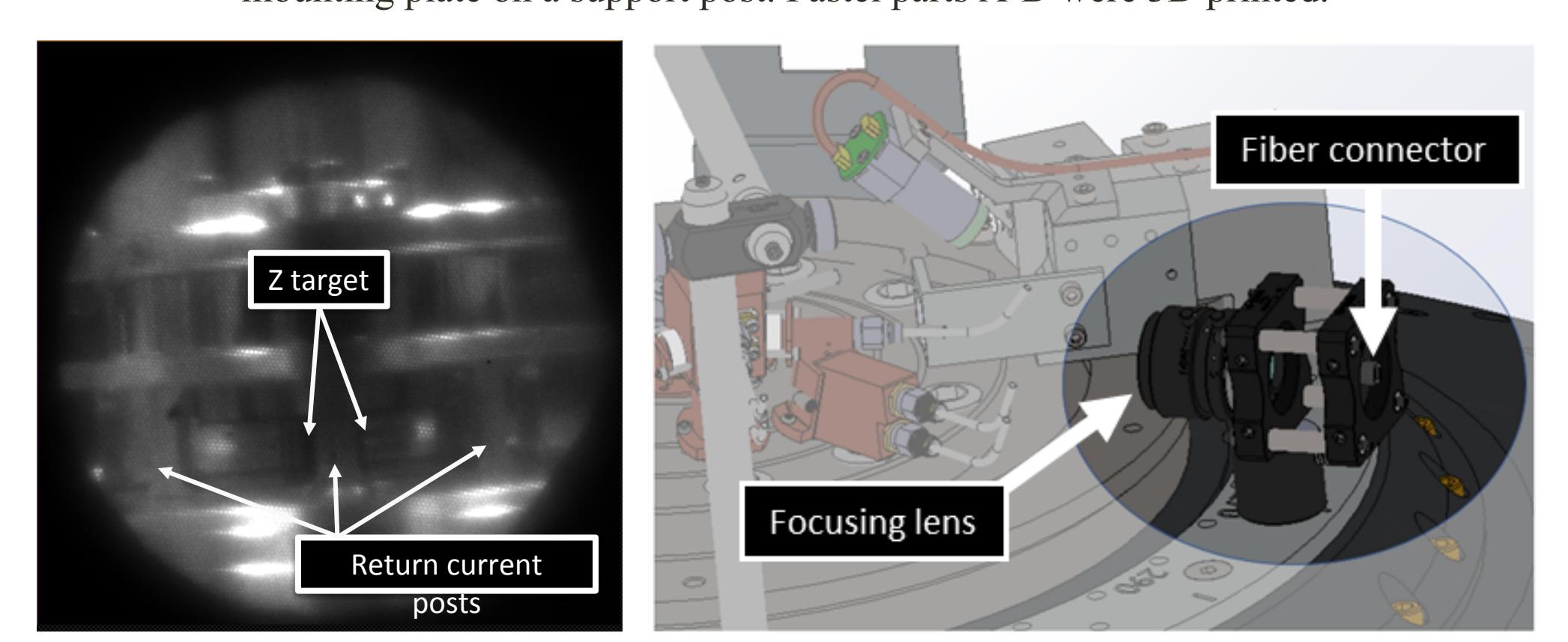
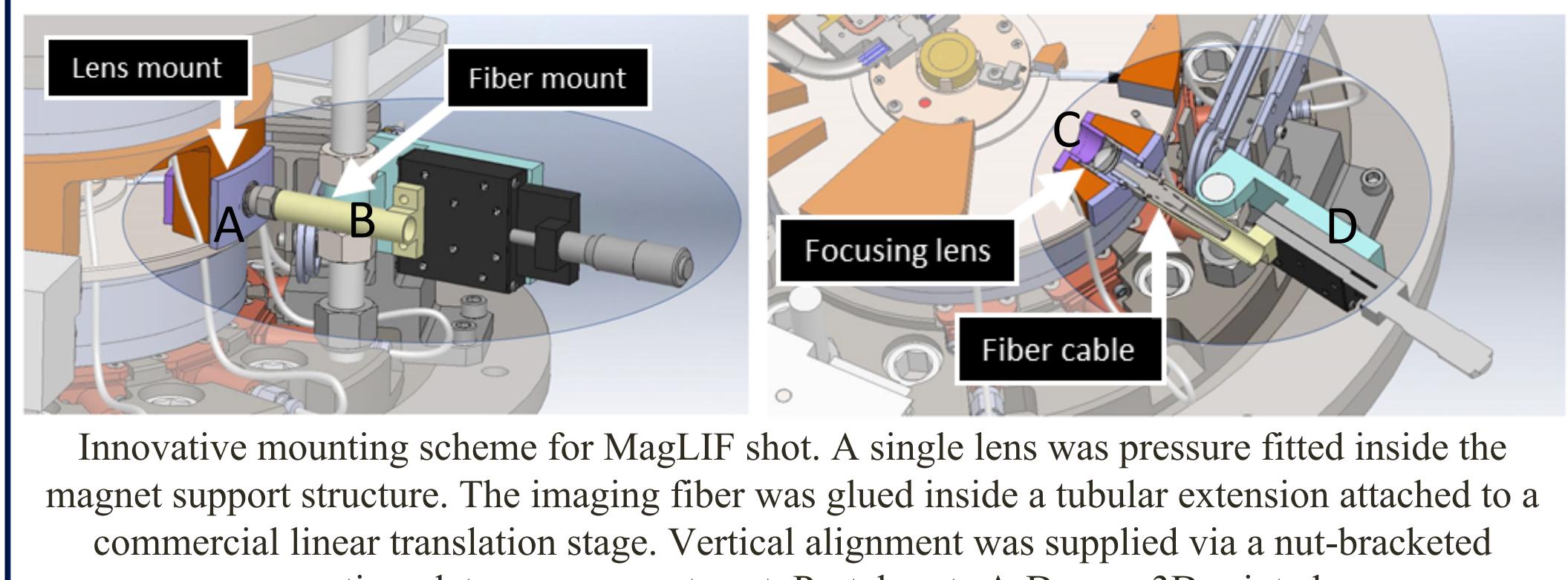
Conceptual rendering of multi-view configuration on one sensor

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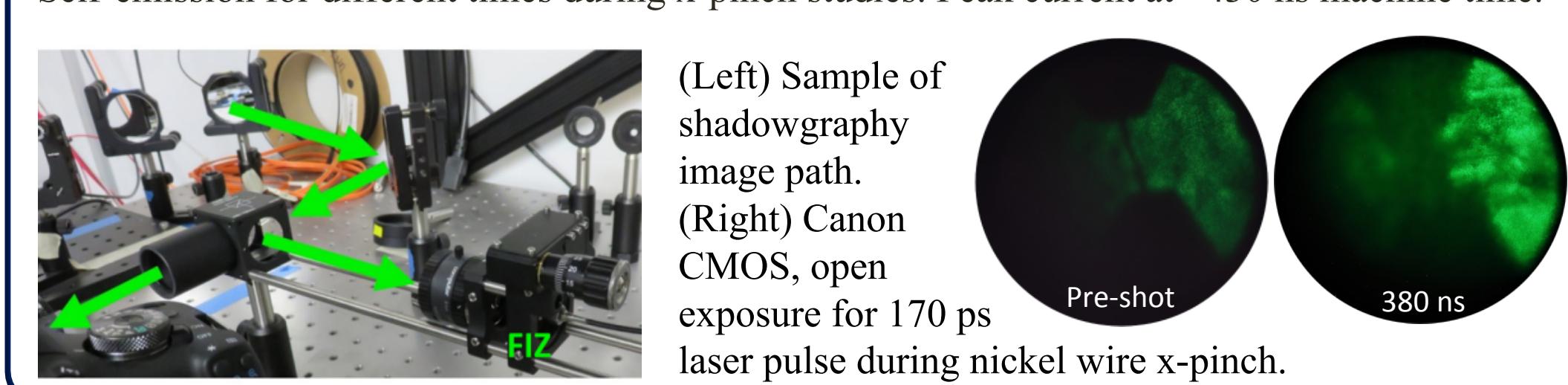
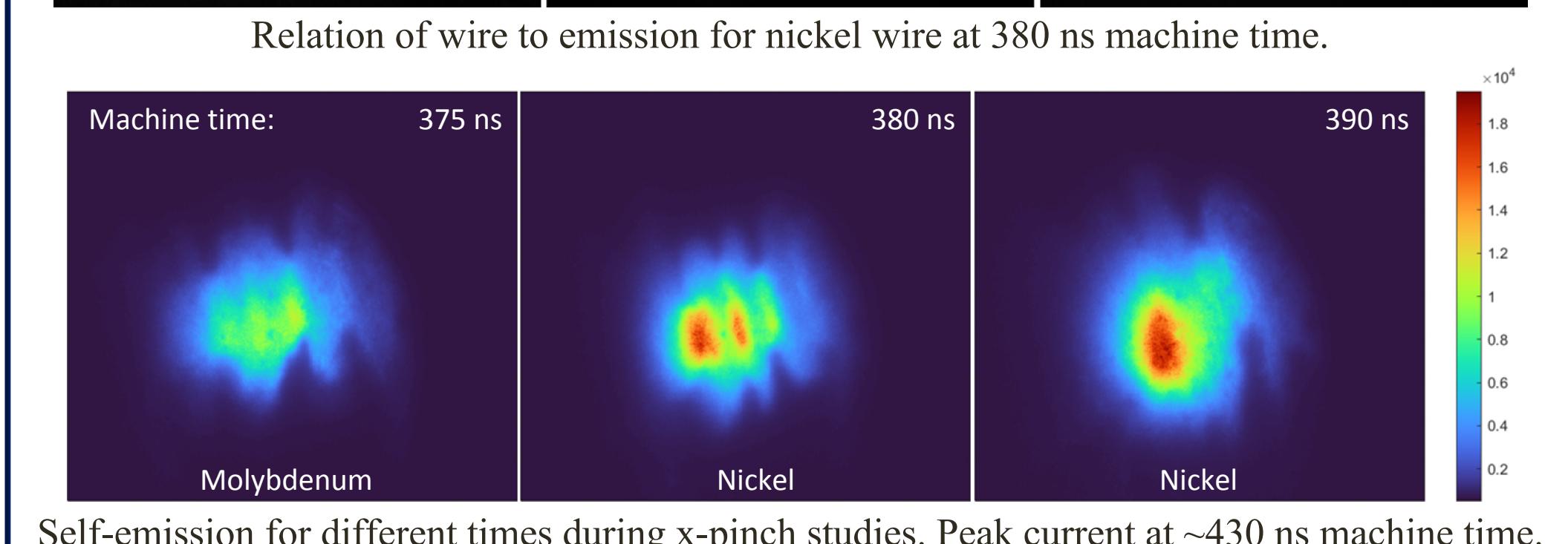
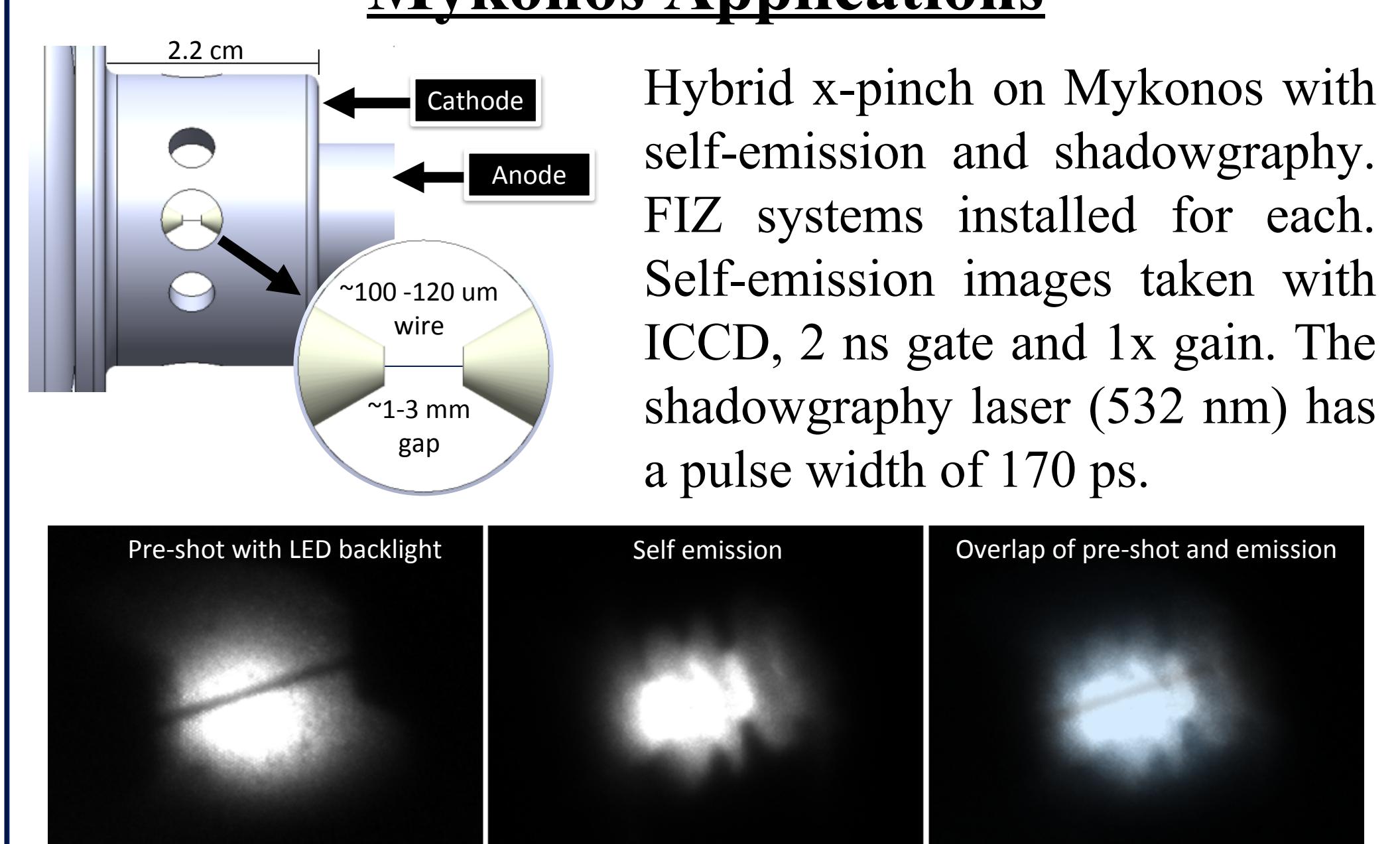


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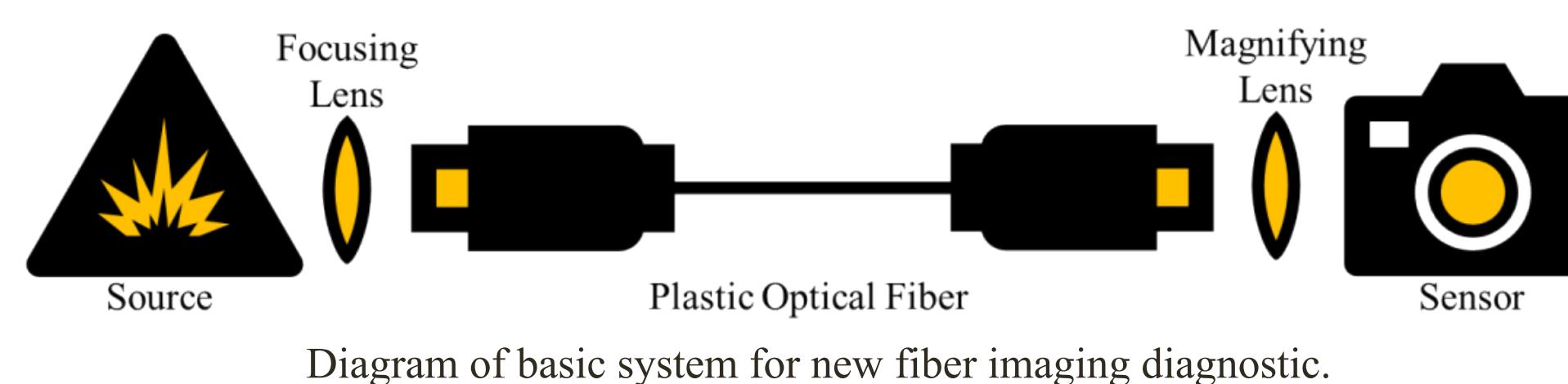
(a) Sandia National Laboratories, (b) University of New Mexico



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- ❖ Fast and easy installation
- ❖ Image multiple positions simultaneously

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FIZ has been fielded on both Z and Mykonos to study magnetized liner inertial fusion (MagLIF) experiments, x-pinches, and the electrothermal instability (ETI).

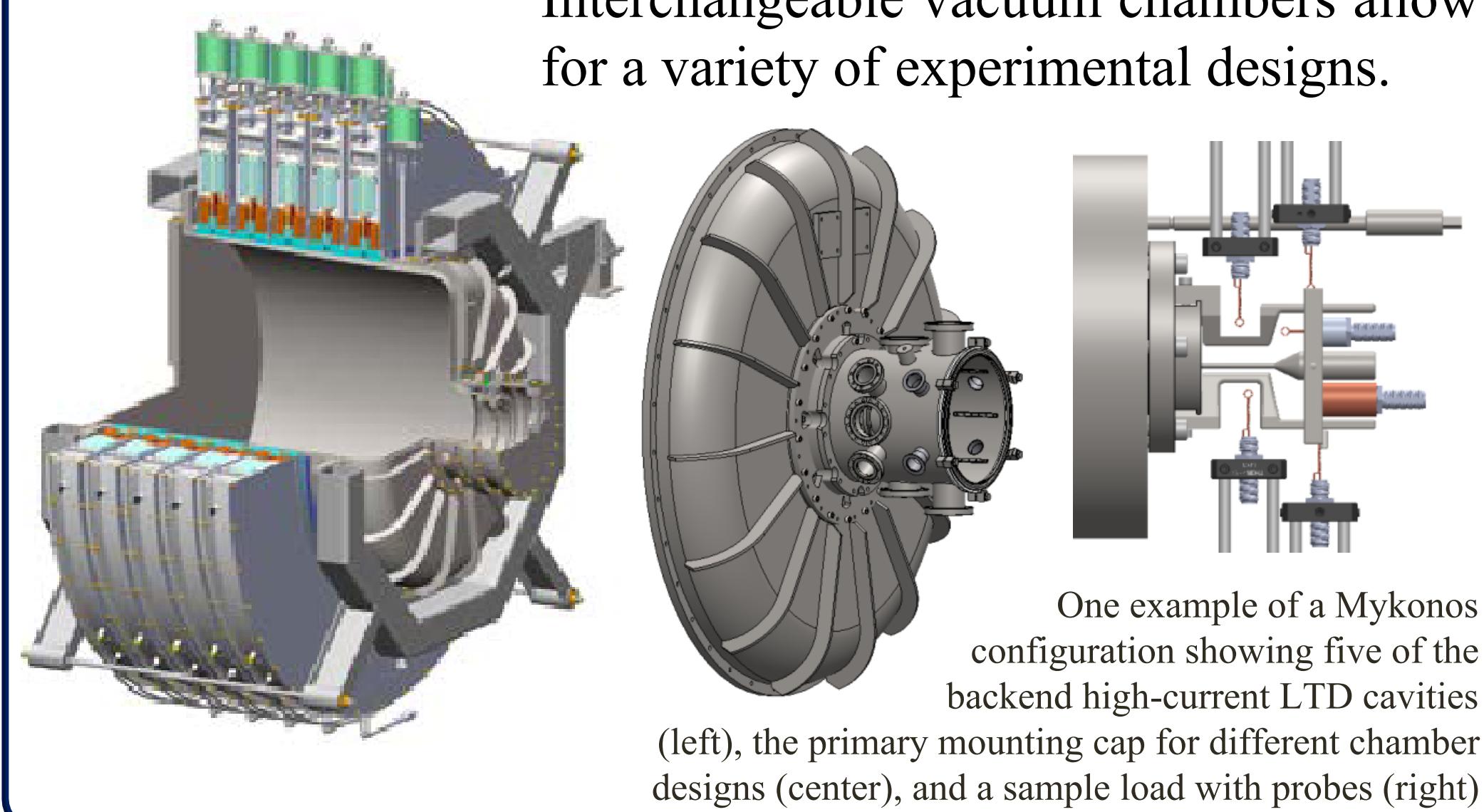
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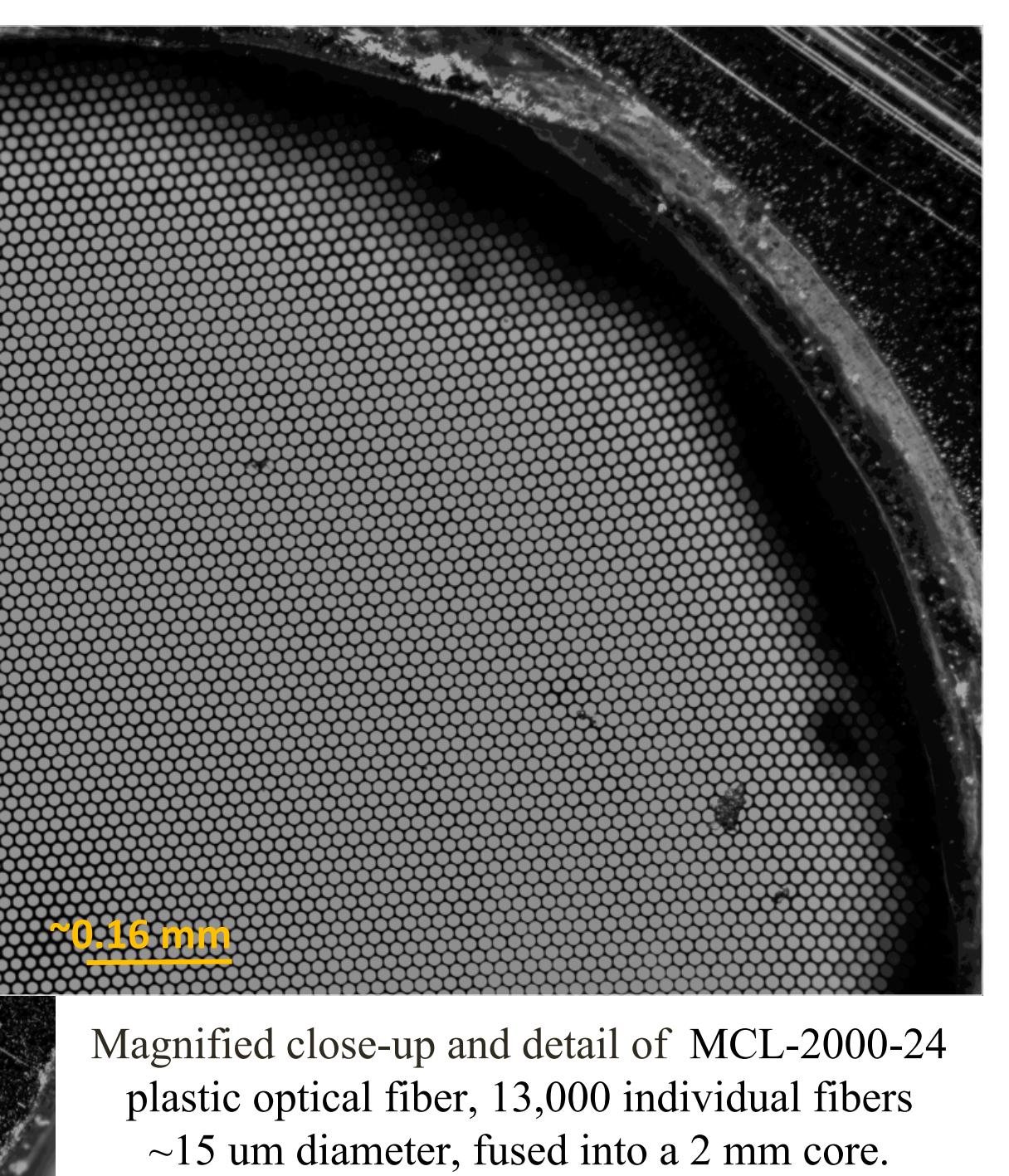
Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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Plastic Optical Fiber

- ❖ MCL-2000-24 (Asahi Kasei Corporation)

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- 13,000 individual fibers, each core ~15 micron in diameter
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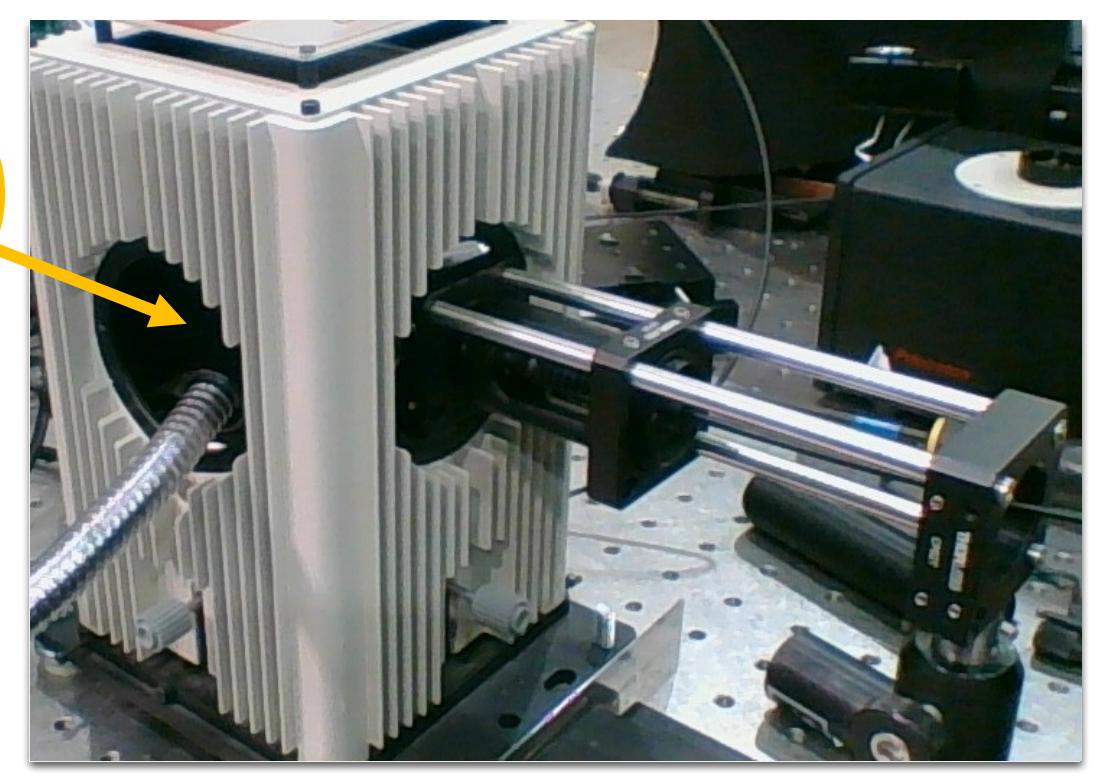


Magnified close-up and detail of MCL-2000-24 plastic optical fiber, 13,000 individual fibers ~15 μm diameter, fused into a 2 mm core.

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- Arc lamp, Xenon
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 - 800 mJ
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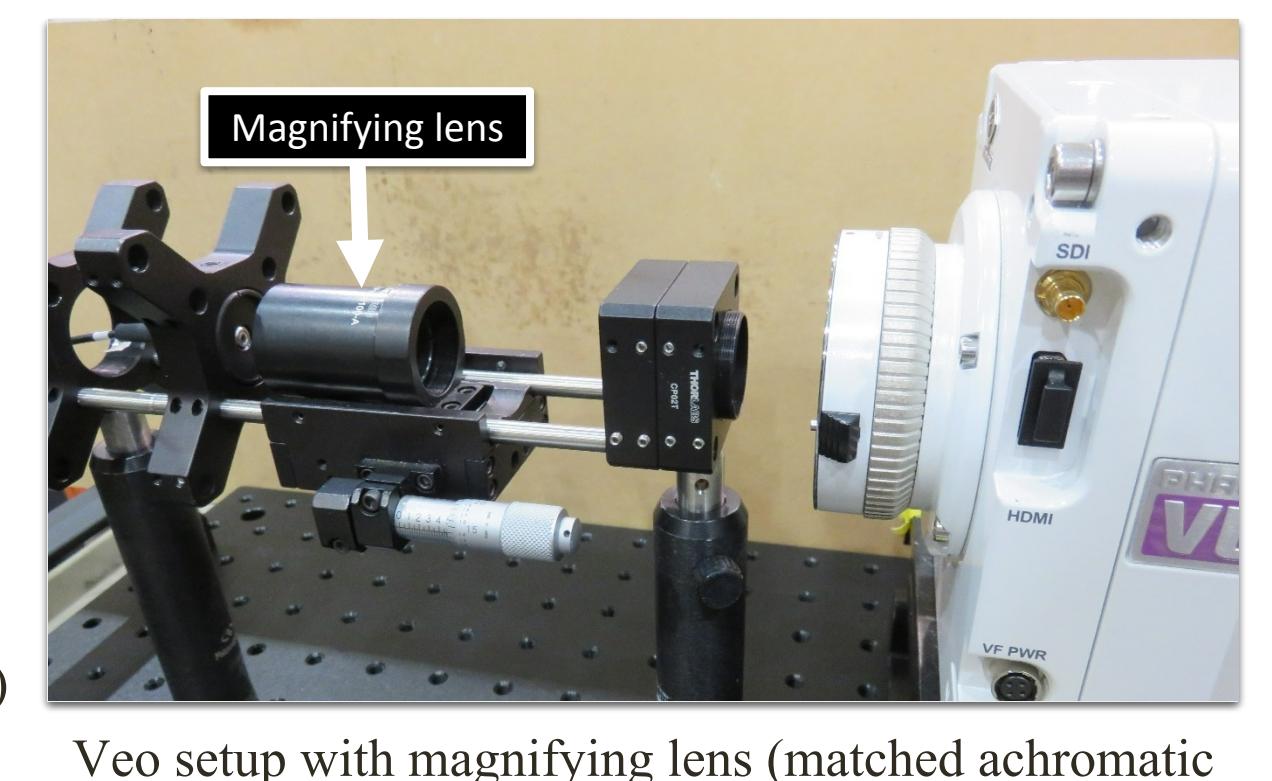


Arc lamp with focusing lens cage system. Detail of interior electrodes.

Sensor Side

- ❖ Focusing lenses

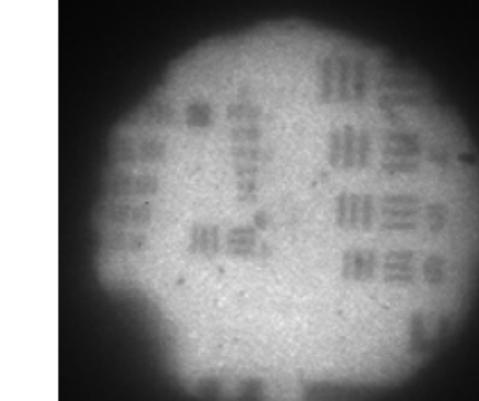
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Veo setup with magnifying lens (matched achromatic doublet pair) imaging directly to the sensor.

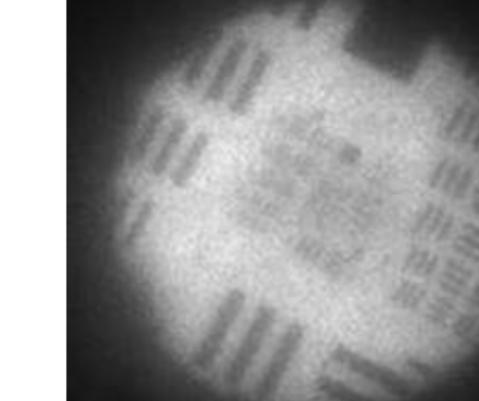
Bench Testing

Small Lens



Resolution (6-1 element):
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FOV: 0.3 mm
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Lens to Fiber: 33 mm
Gate: 300 μs

Wide Angle

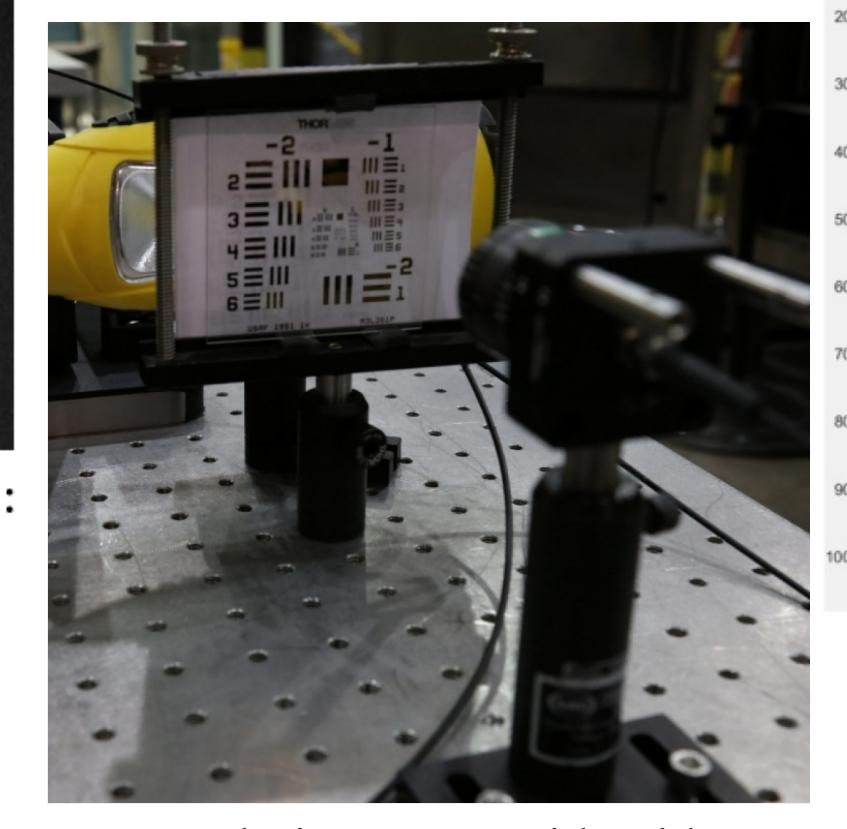


Resolution (-1-5 element):
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Objective

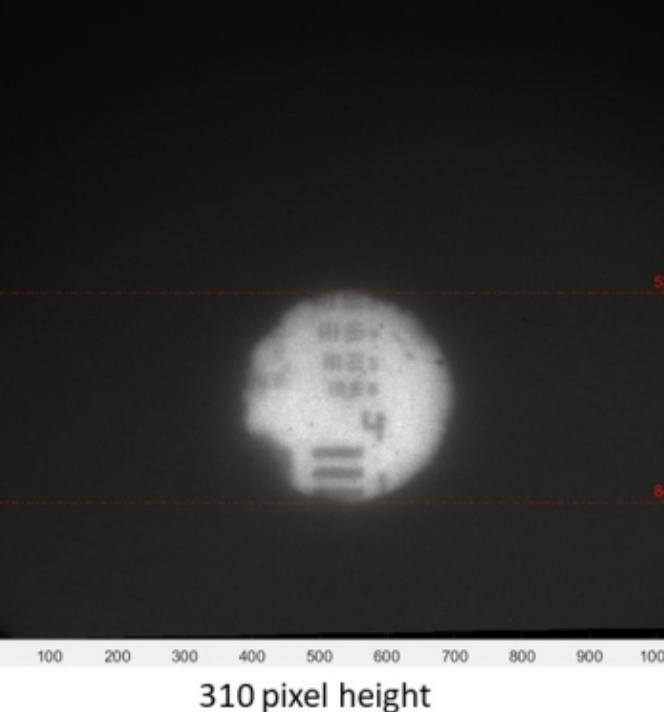


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Resolution target with wide angle lens and LED

FOV Test Image



FOV calculation based on USAF resolution target

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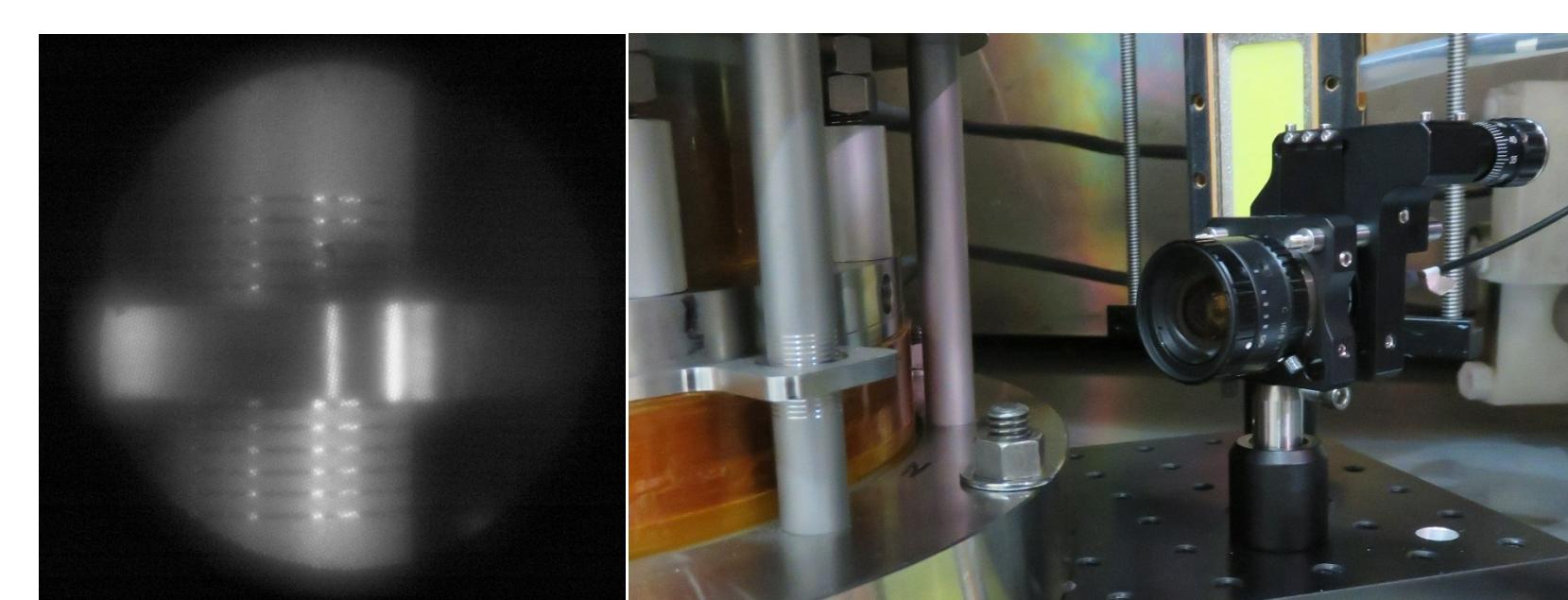
(cutting, connectorizing and polishing)

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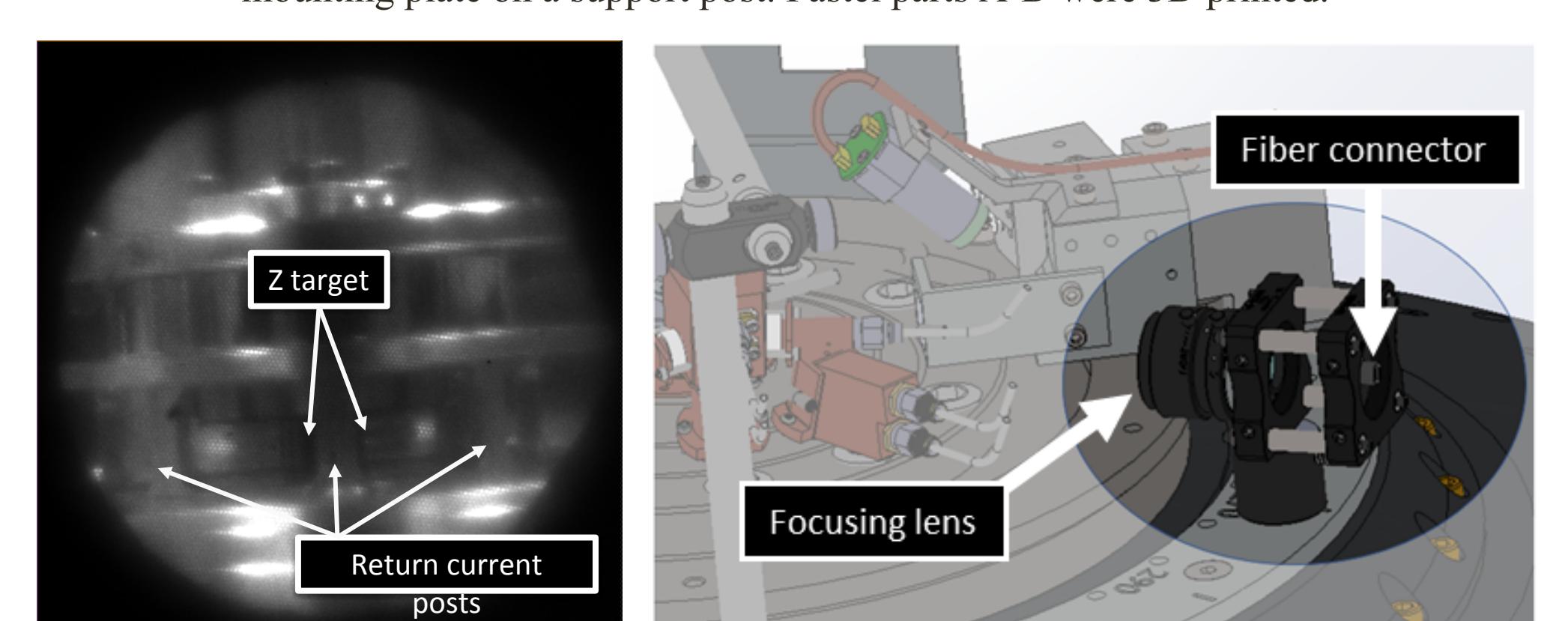
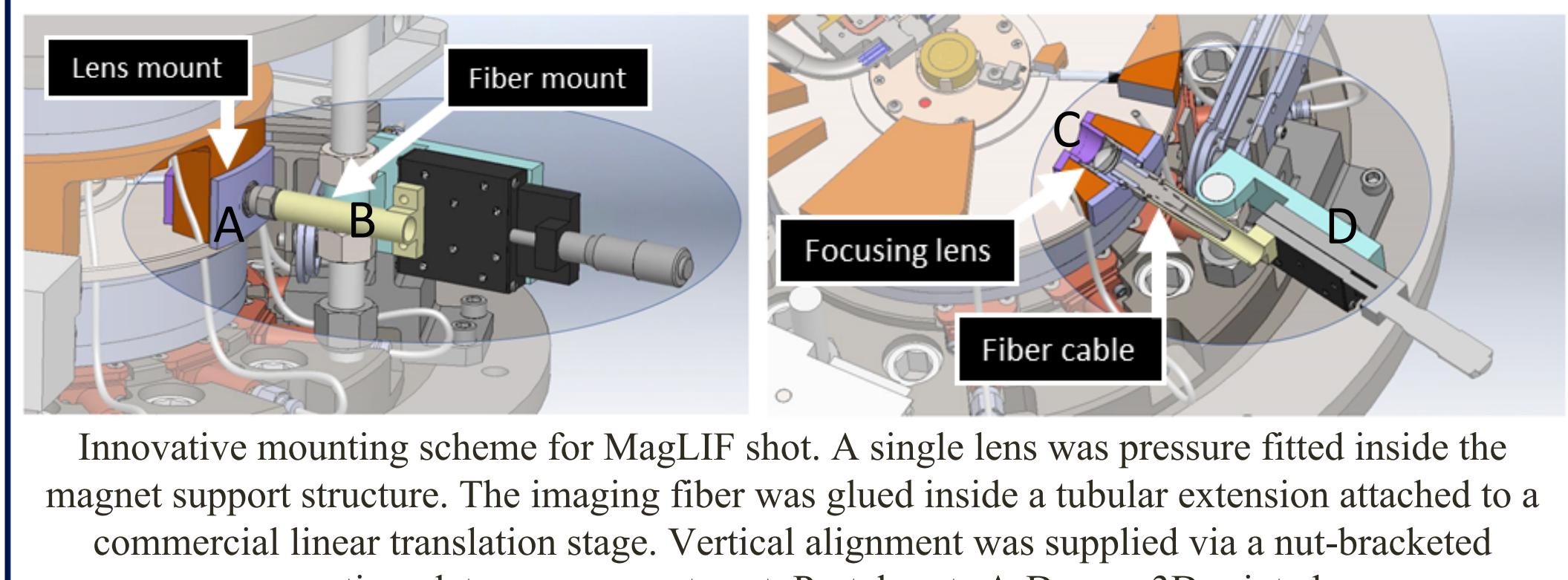
Diversify pulsed power devices and applications
Troubleshooting MagLIF coils in vacuum



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Mechanical polishing

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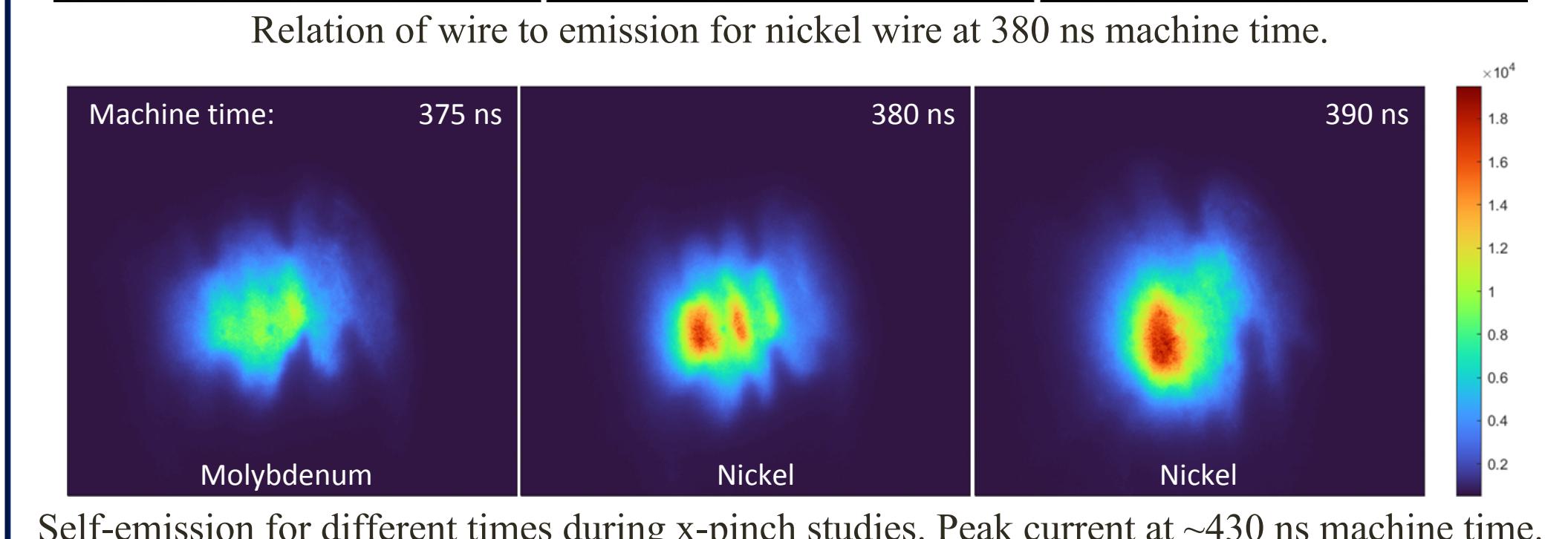
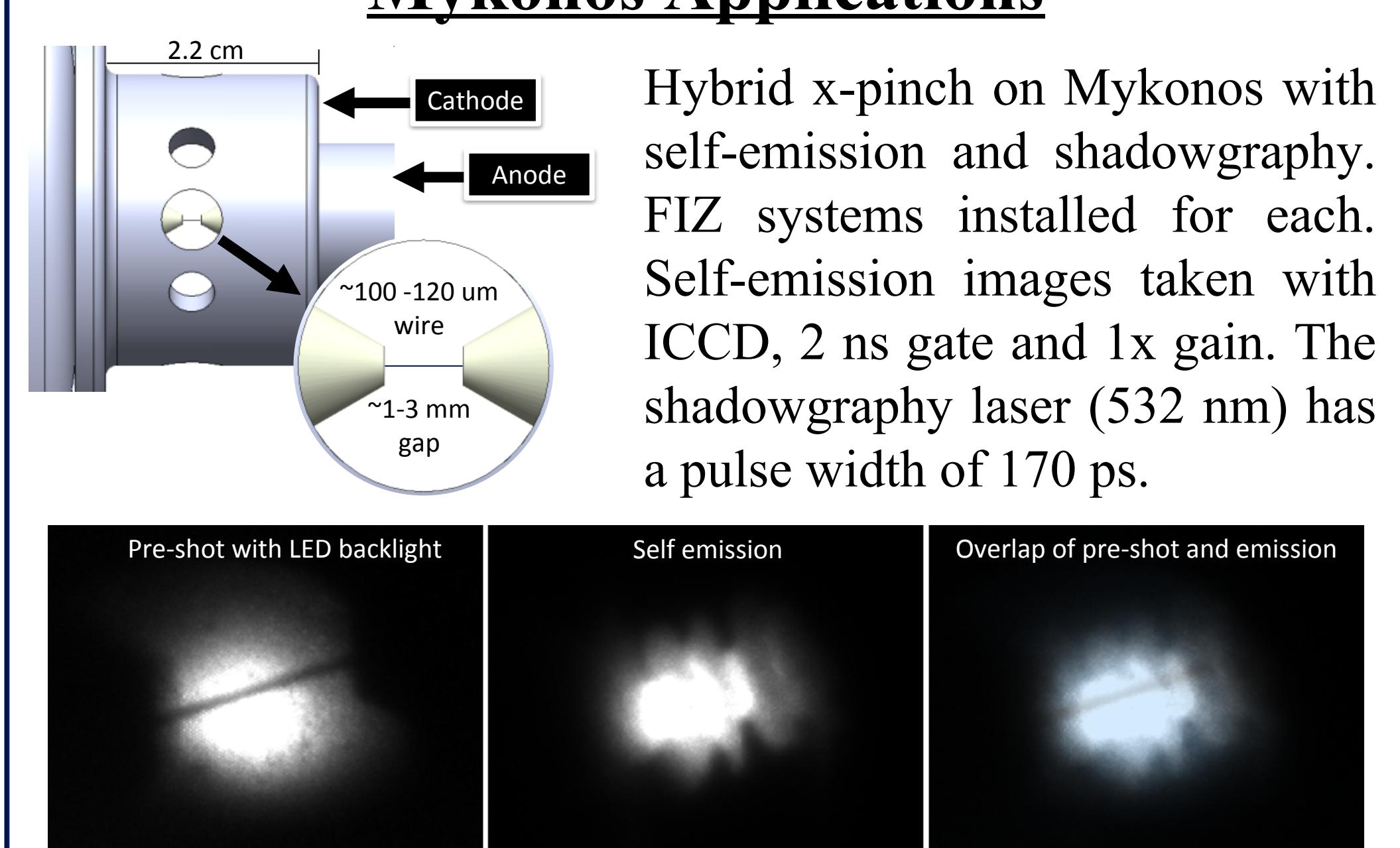


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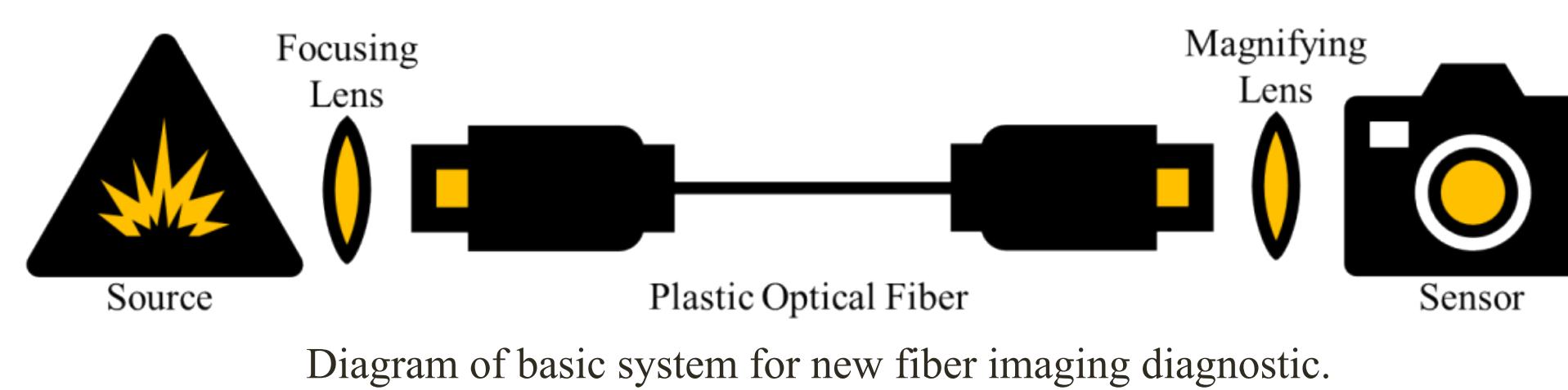
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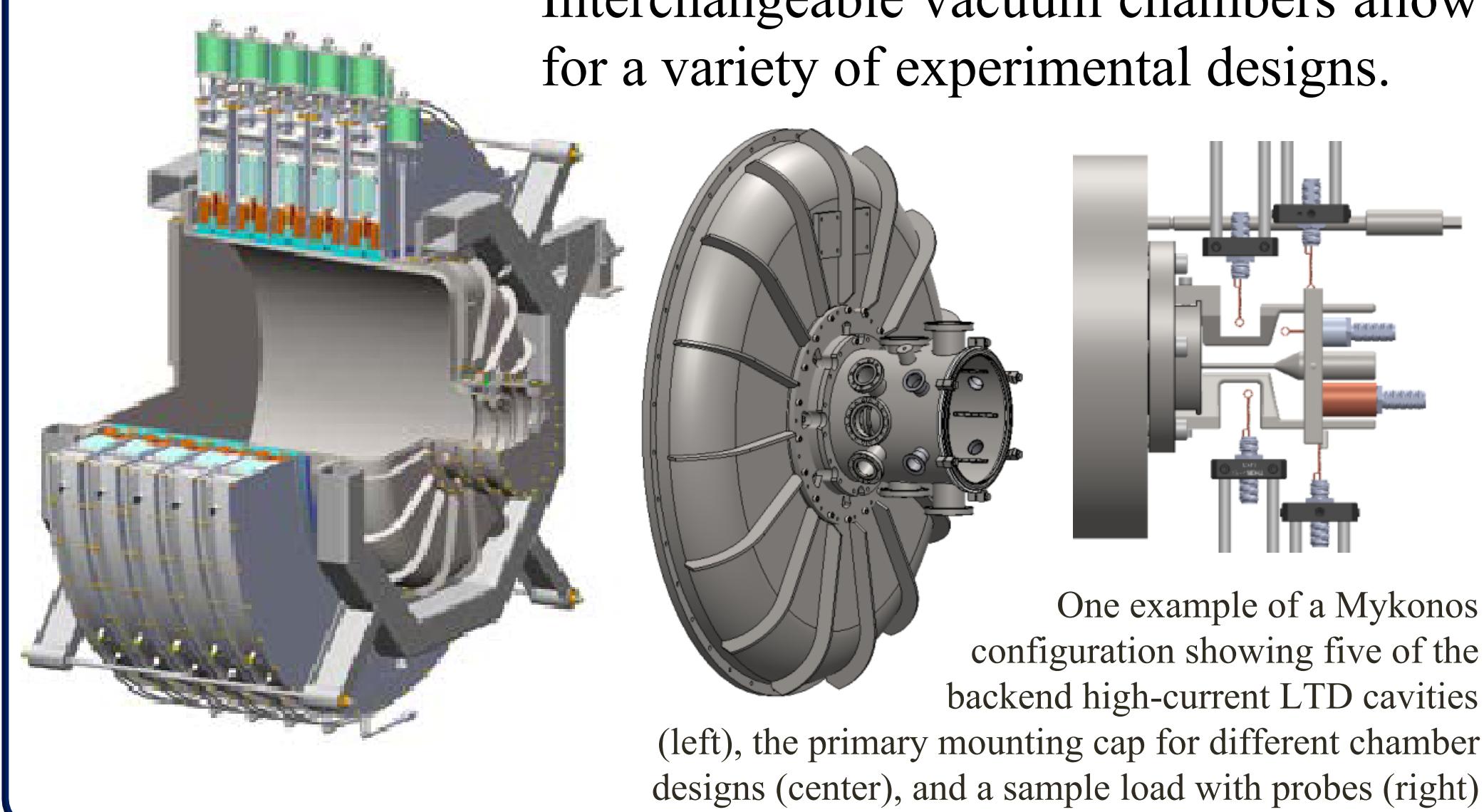
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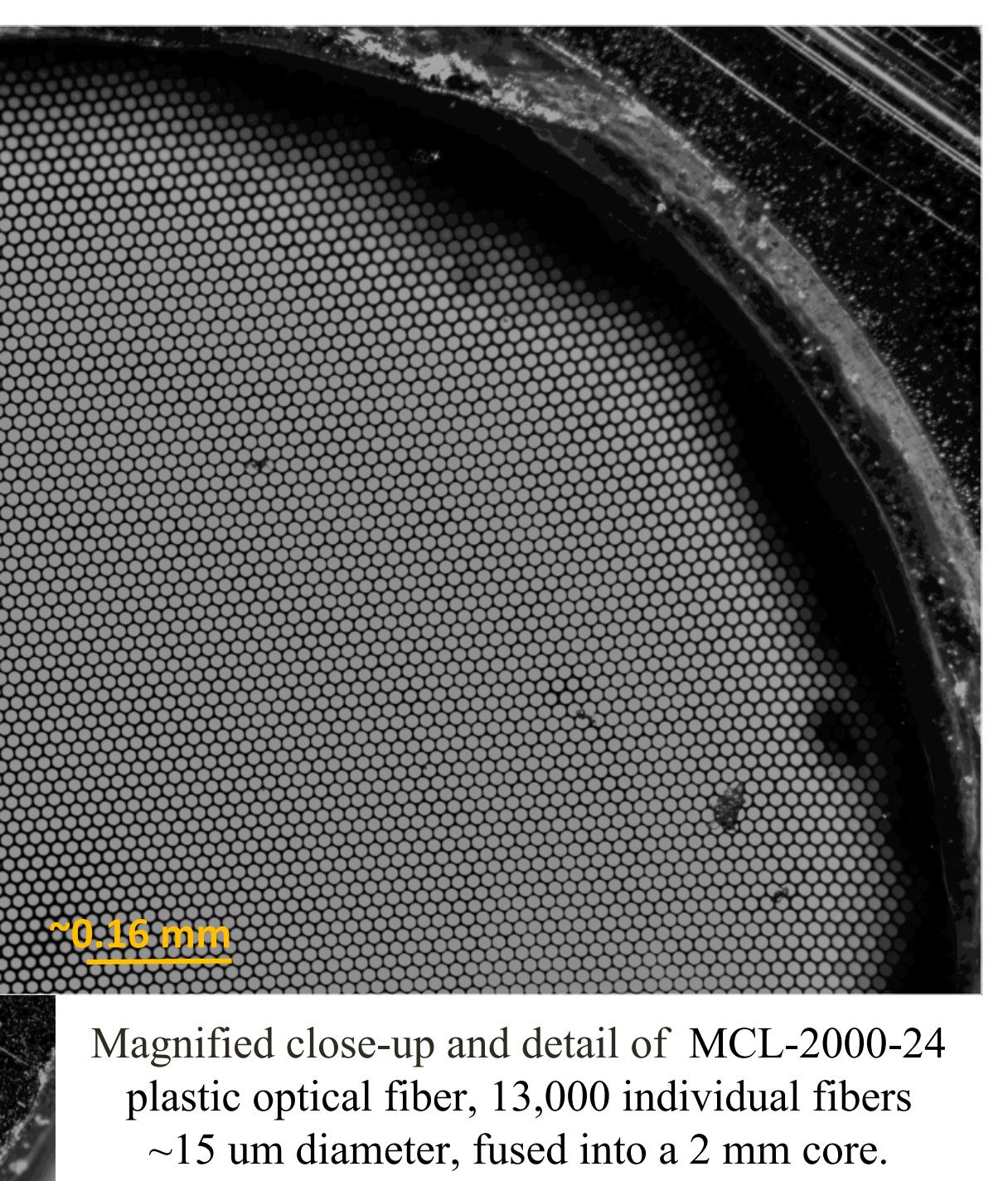
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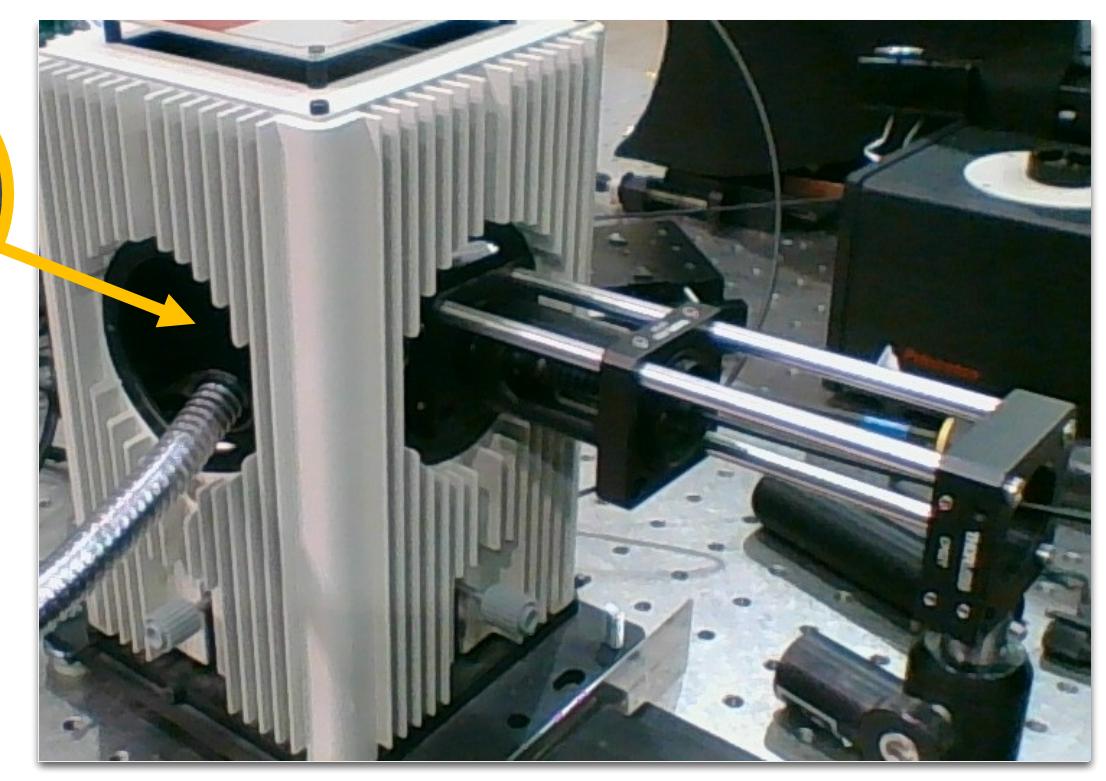


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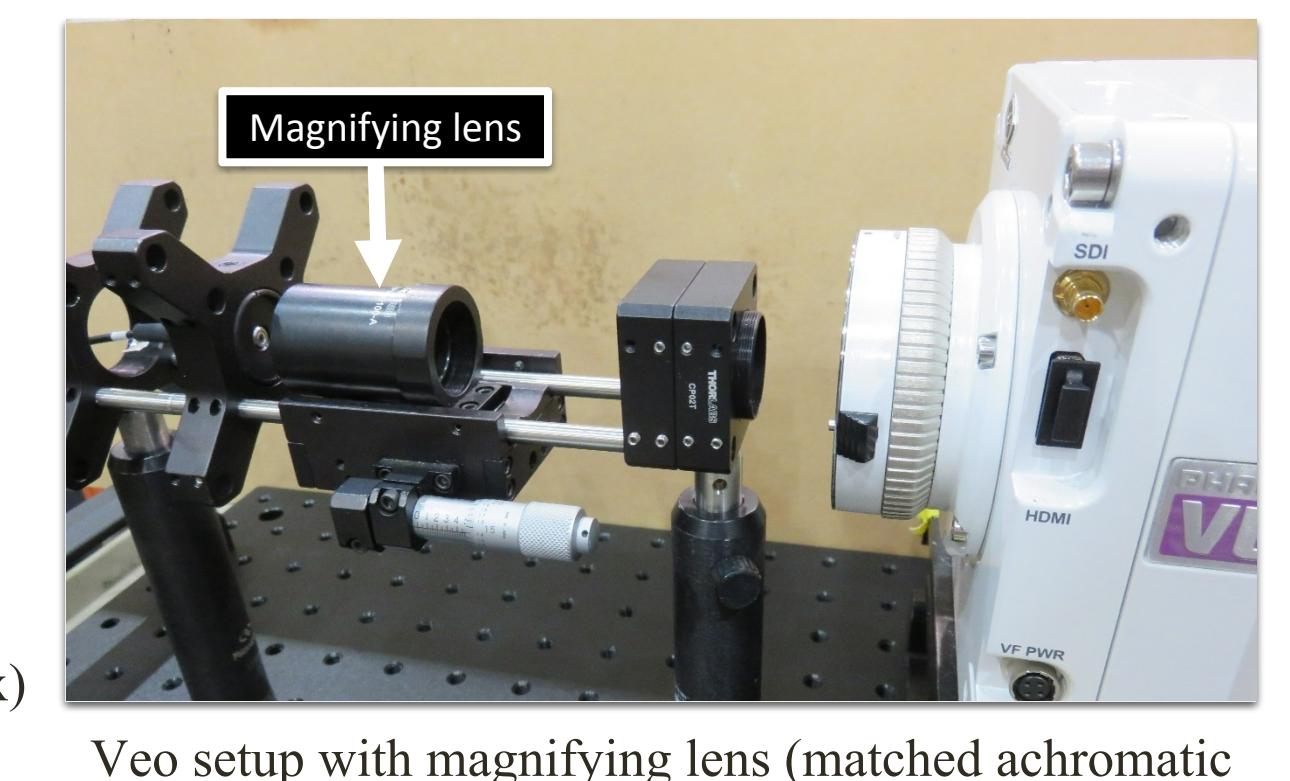


Arc lamp with focusing lens cage system. Detail of interior electrodes.

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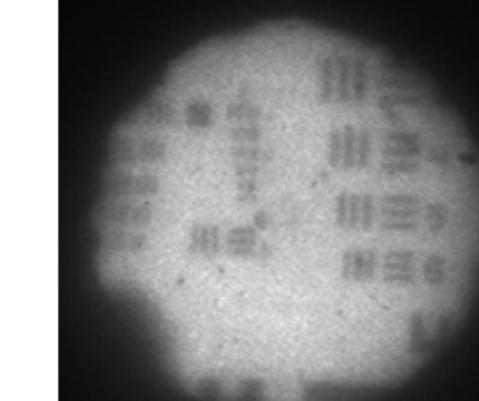
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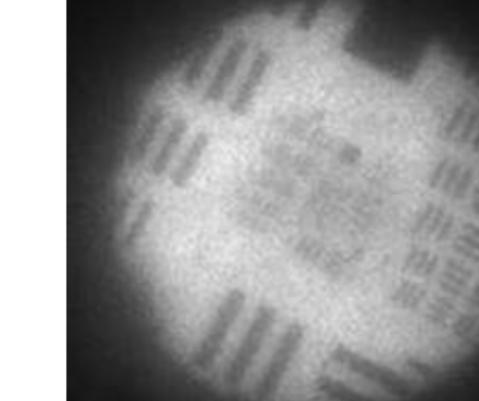
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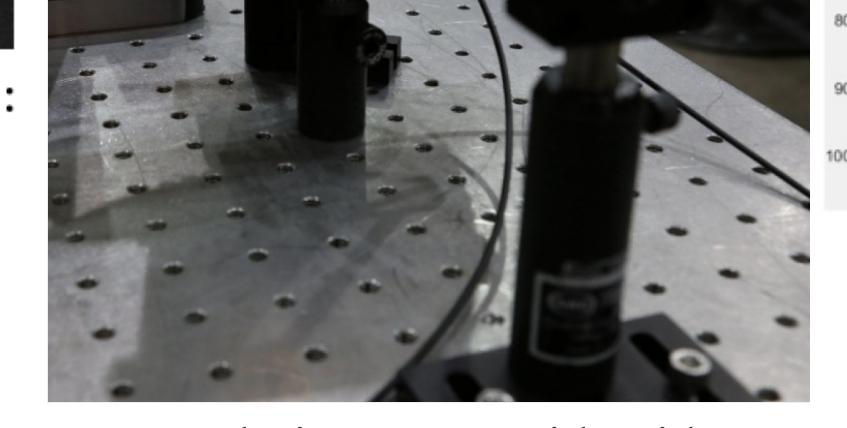


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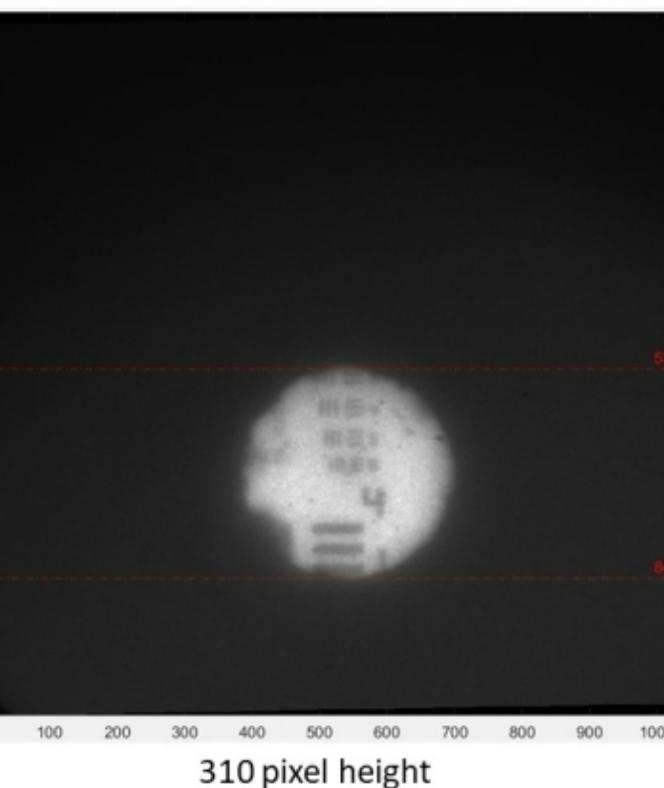


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Resolution target with wide angle lens and LED

FOV Test Image



FOV calculation based on USAF resolution target

• Resolution (4-1 element) is 31.25 μm (16 lp/mm)

• Average width is 31.5 pixels

• Conversion: 0.99 $\mu\text{m}/\text{pixel}$

• FOV for this image: $0.99 \times 310 = 306.9 \mu\text{m}$

310 pixel height

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High resolution fiber imaging for pulsed power experiments

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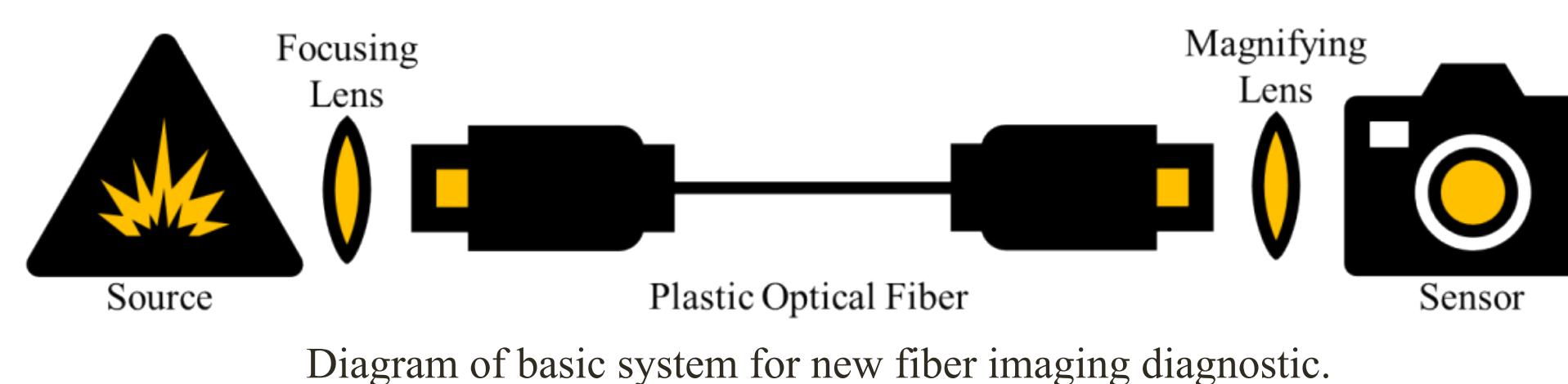
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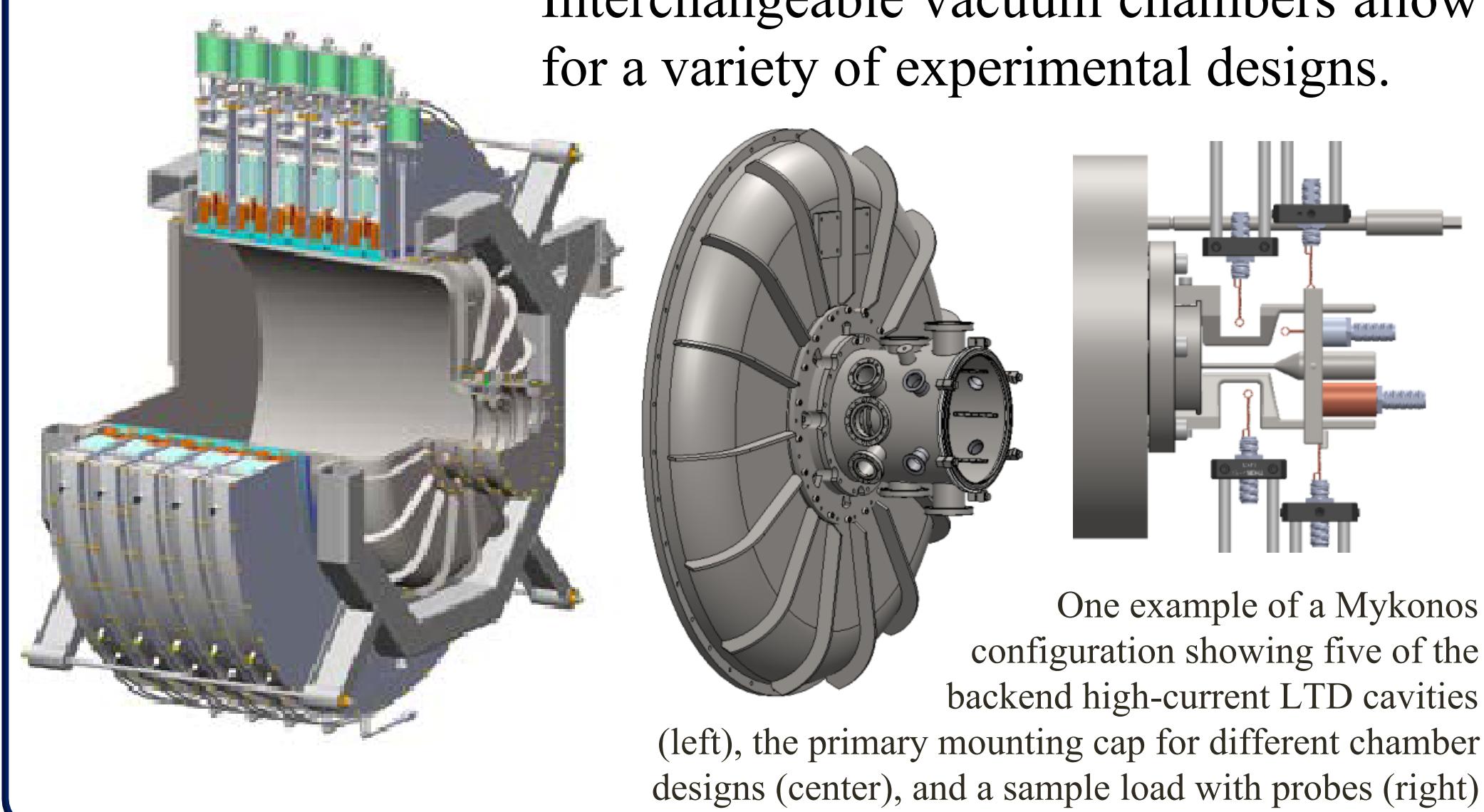
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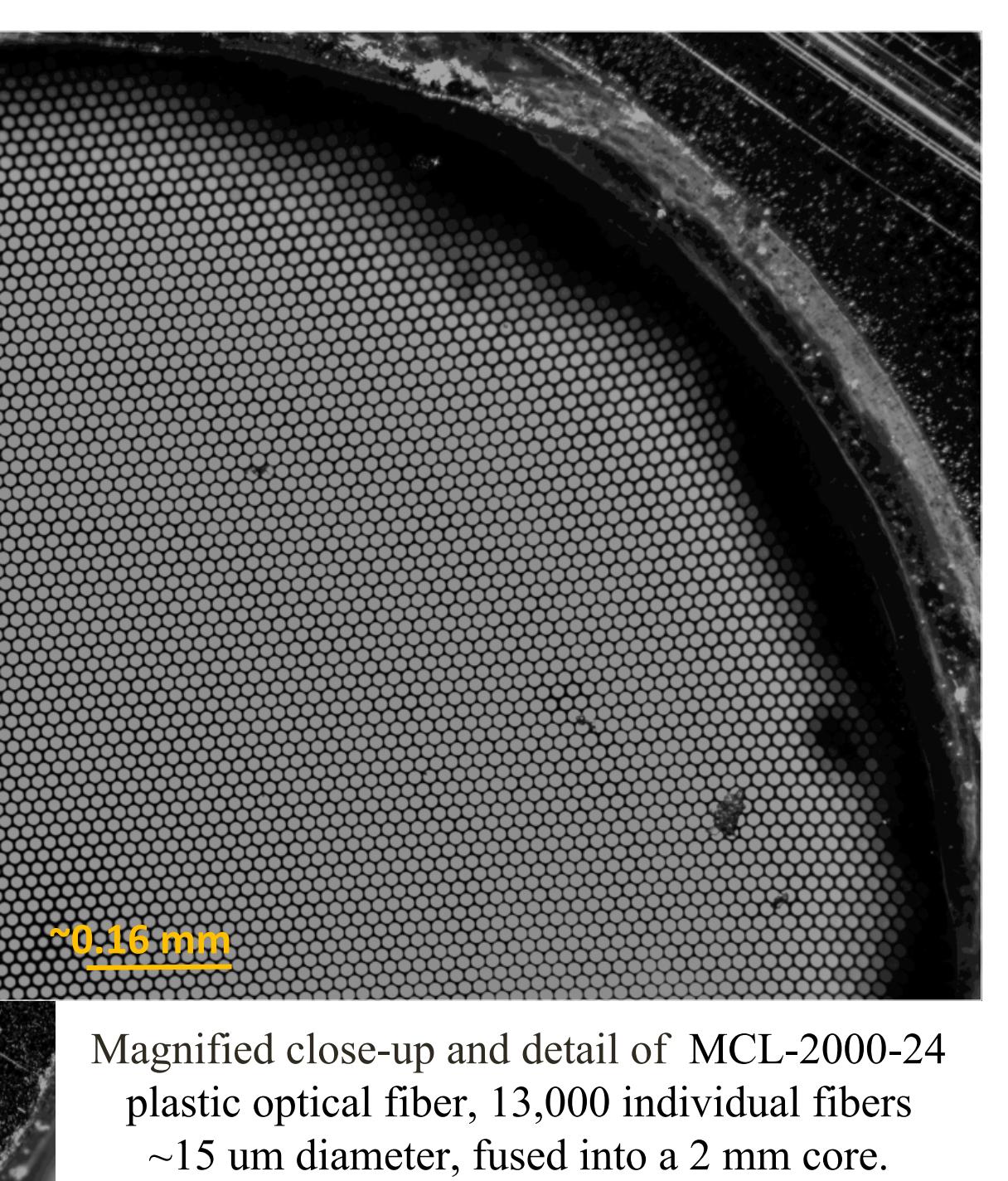
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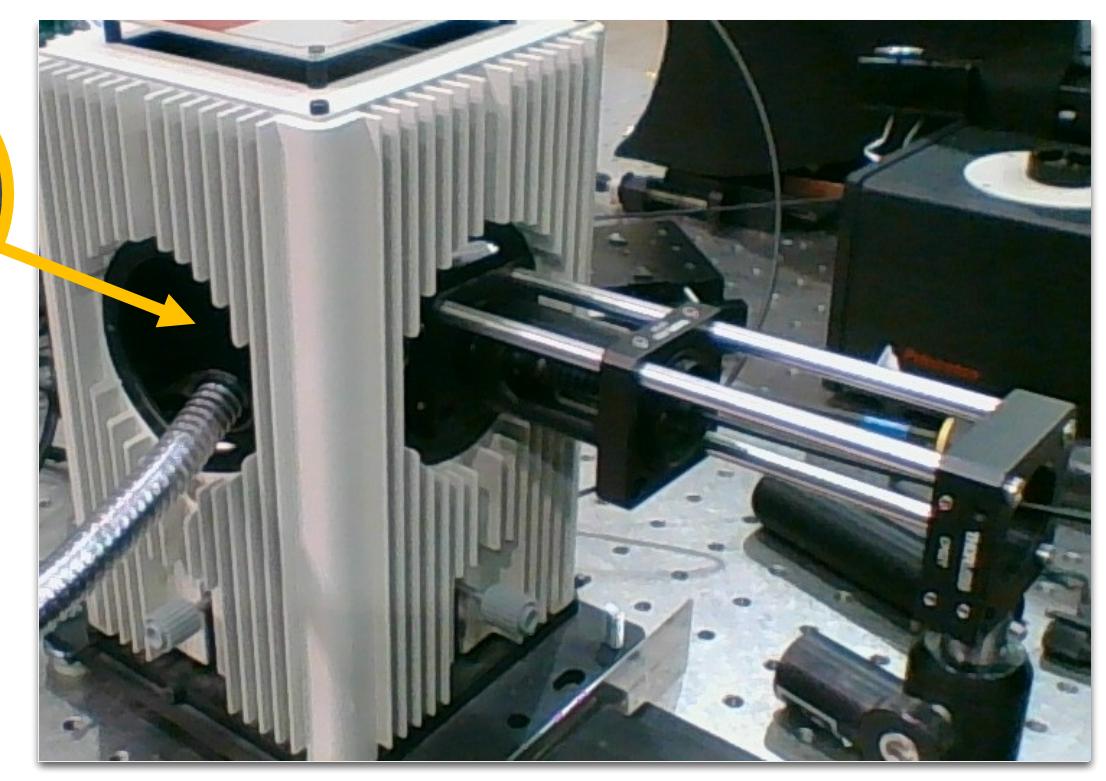


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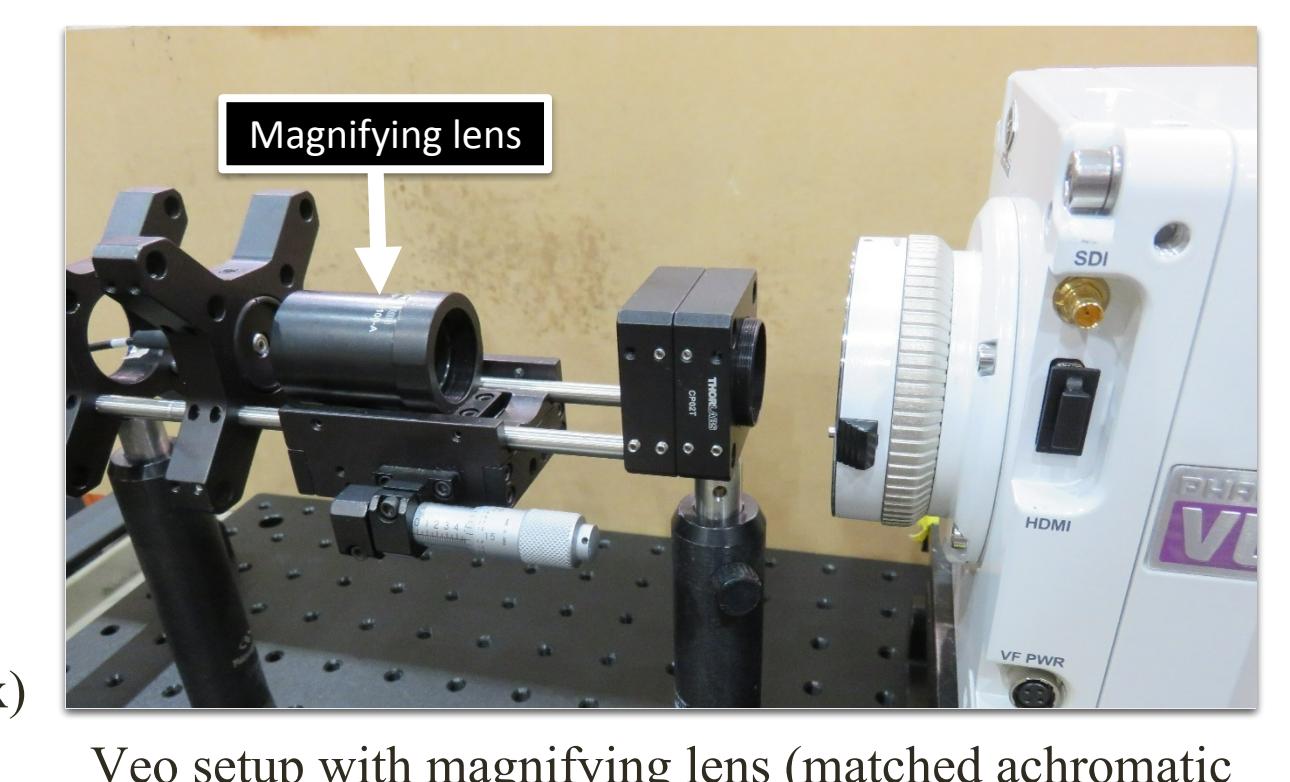


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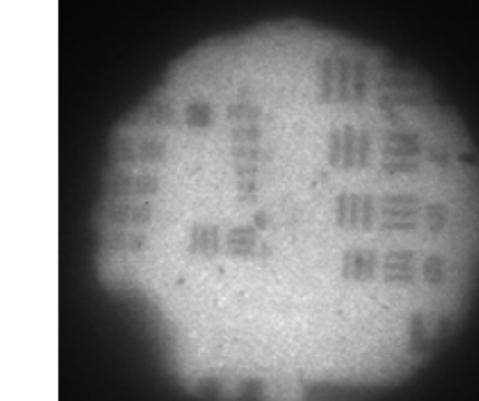
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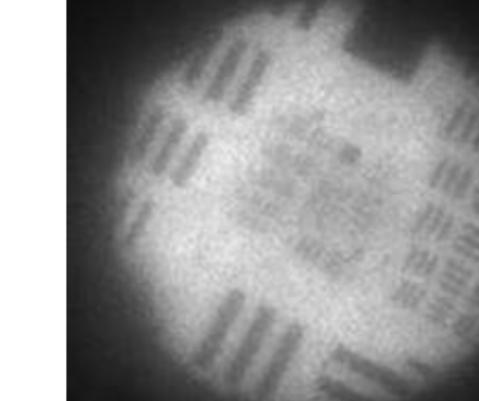
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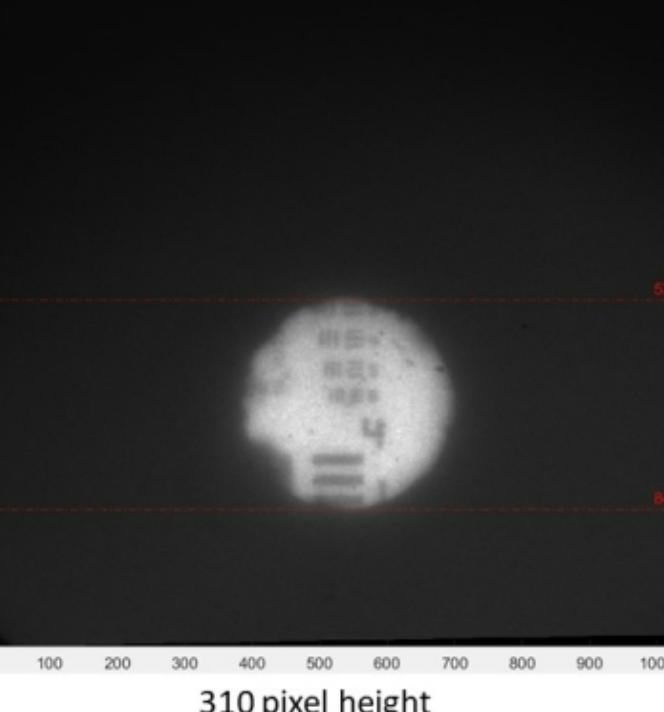


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In-house fiber production

(cutting, connectorizing and polishing)

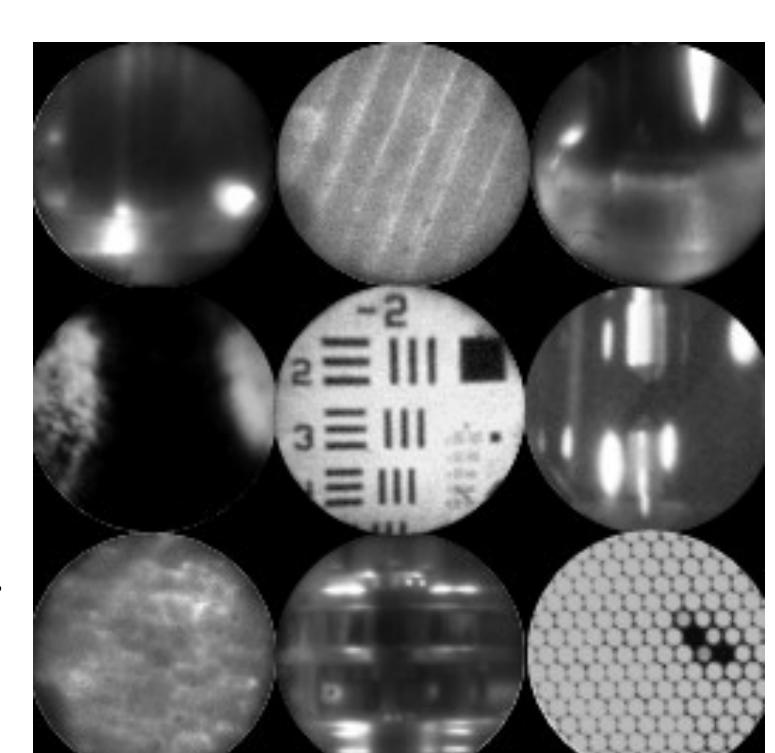
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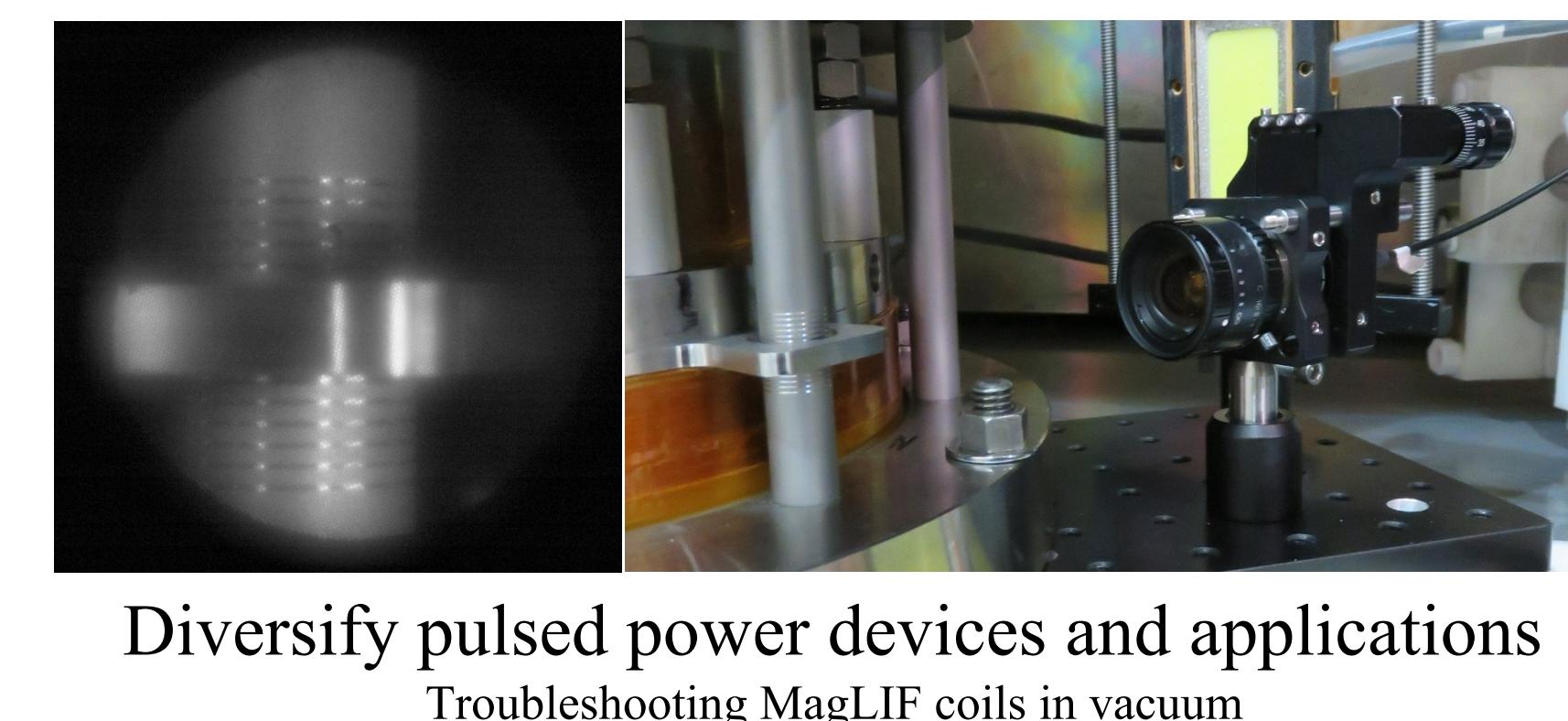
Build different fiber arrays to:

- Maximize the sensor
- Vary time and views
- Illuminate, filter and image in parallel
- Increase FOV



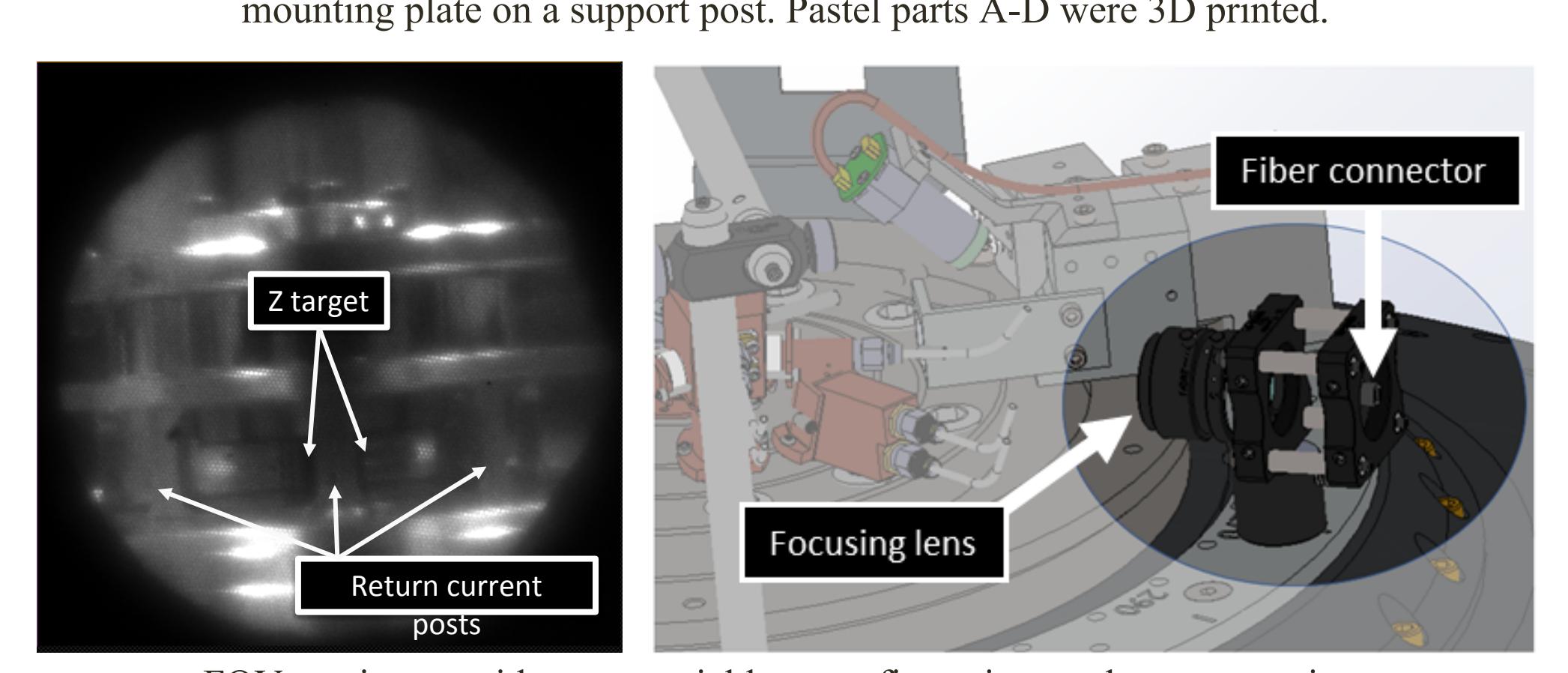
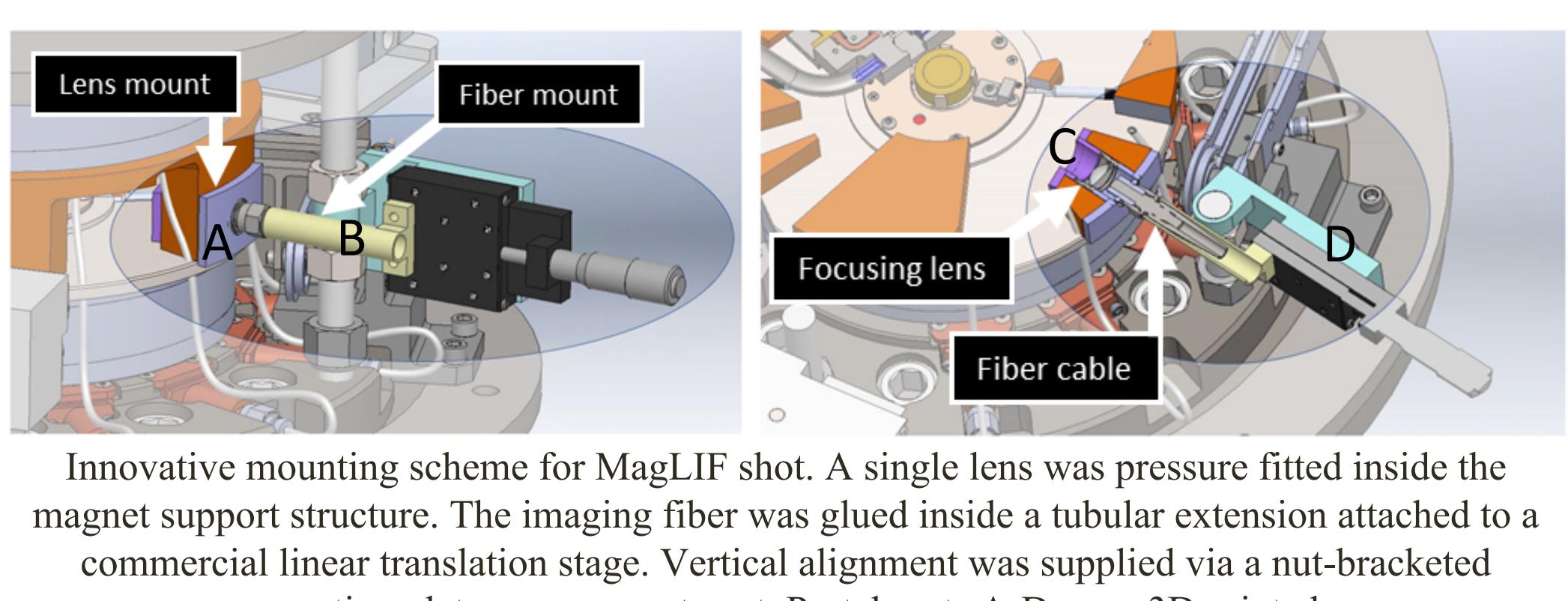
Conceptual rendering of multi-view configuration on one sensor

Potential Advancements



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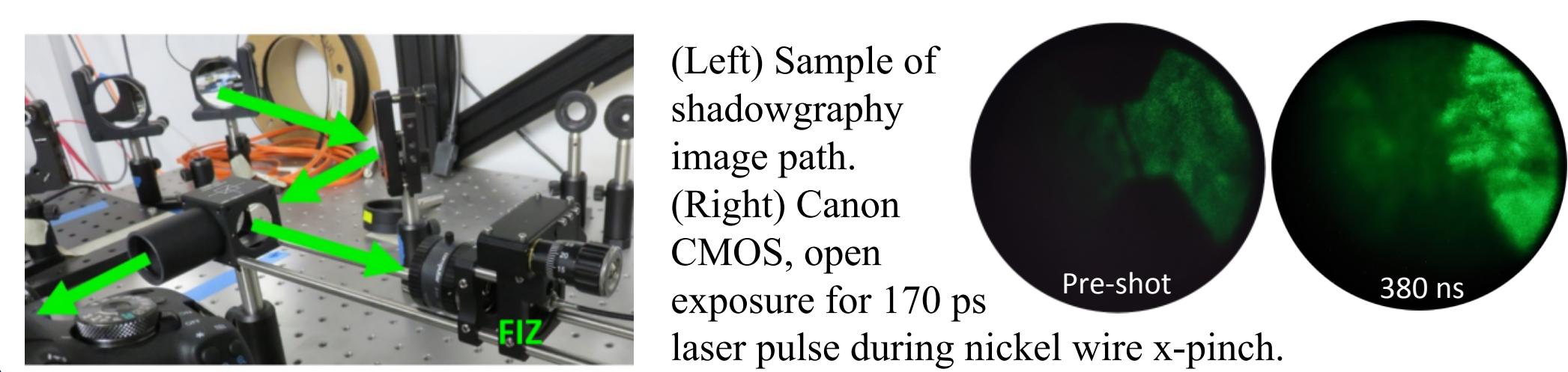
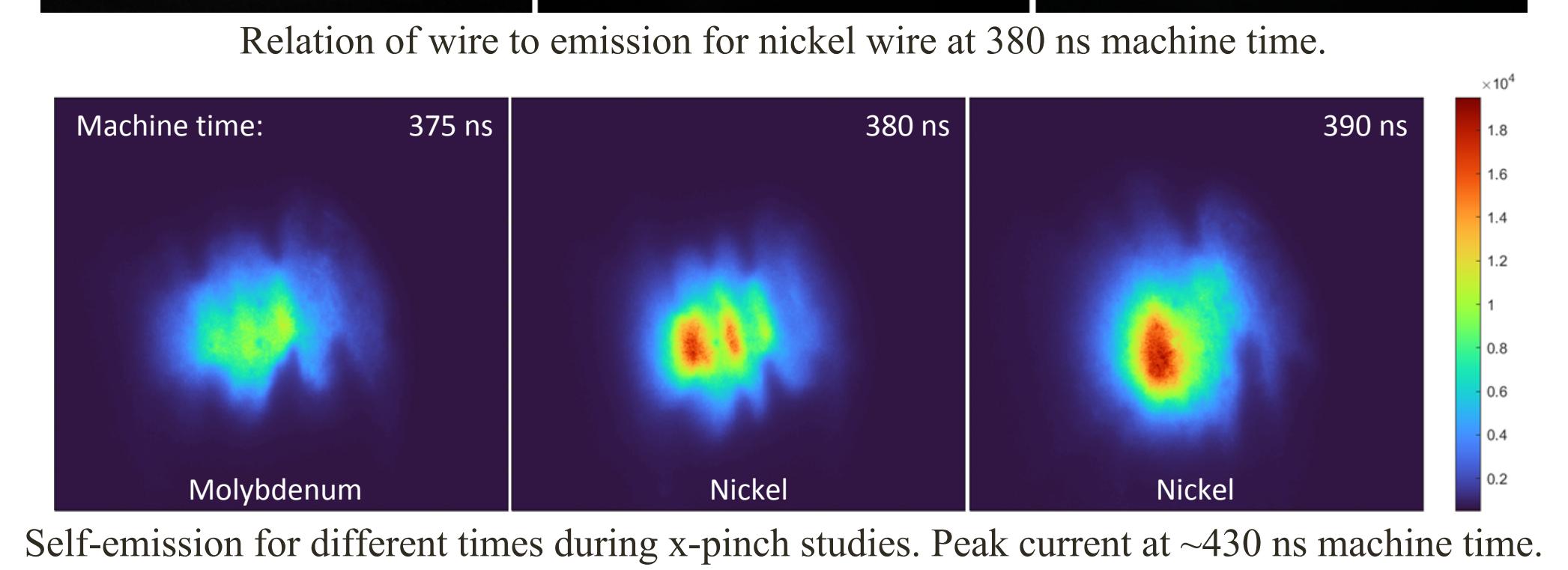
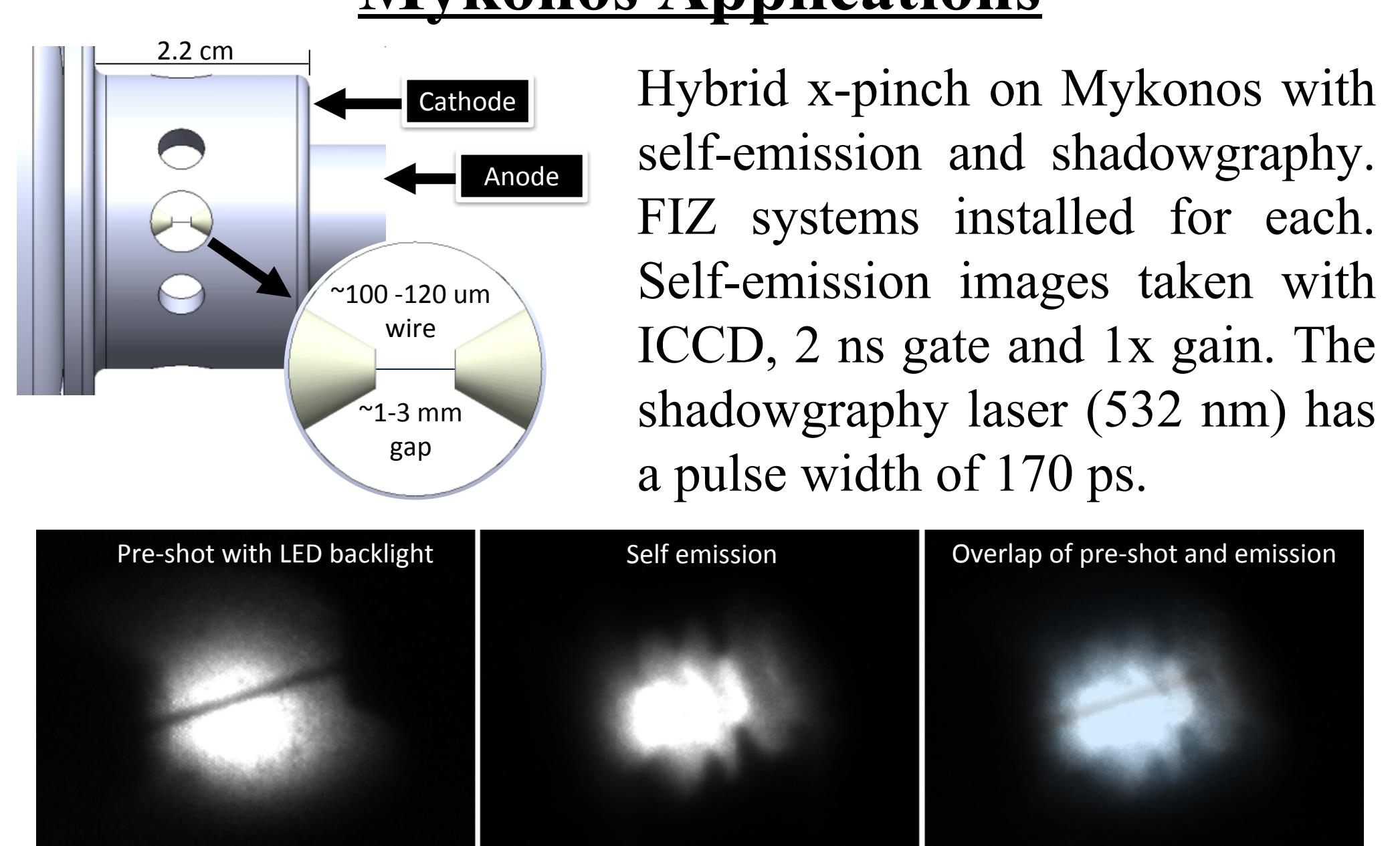


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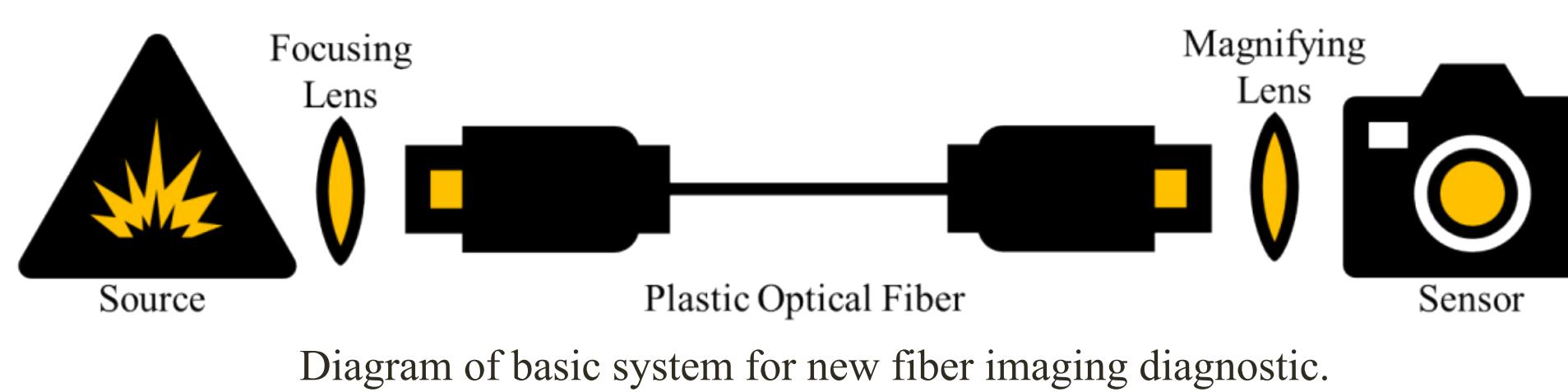
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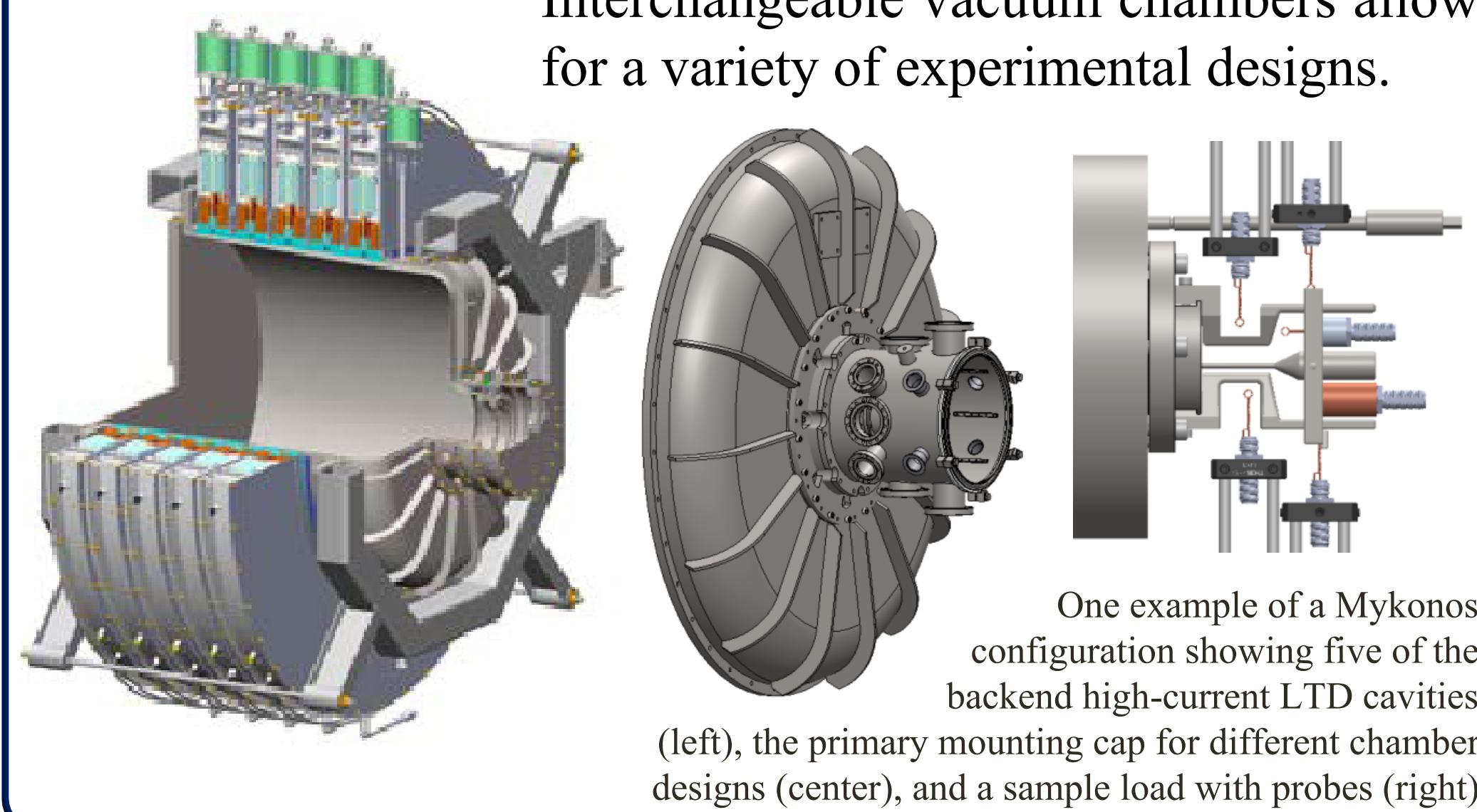
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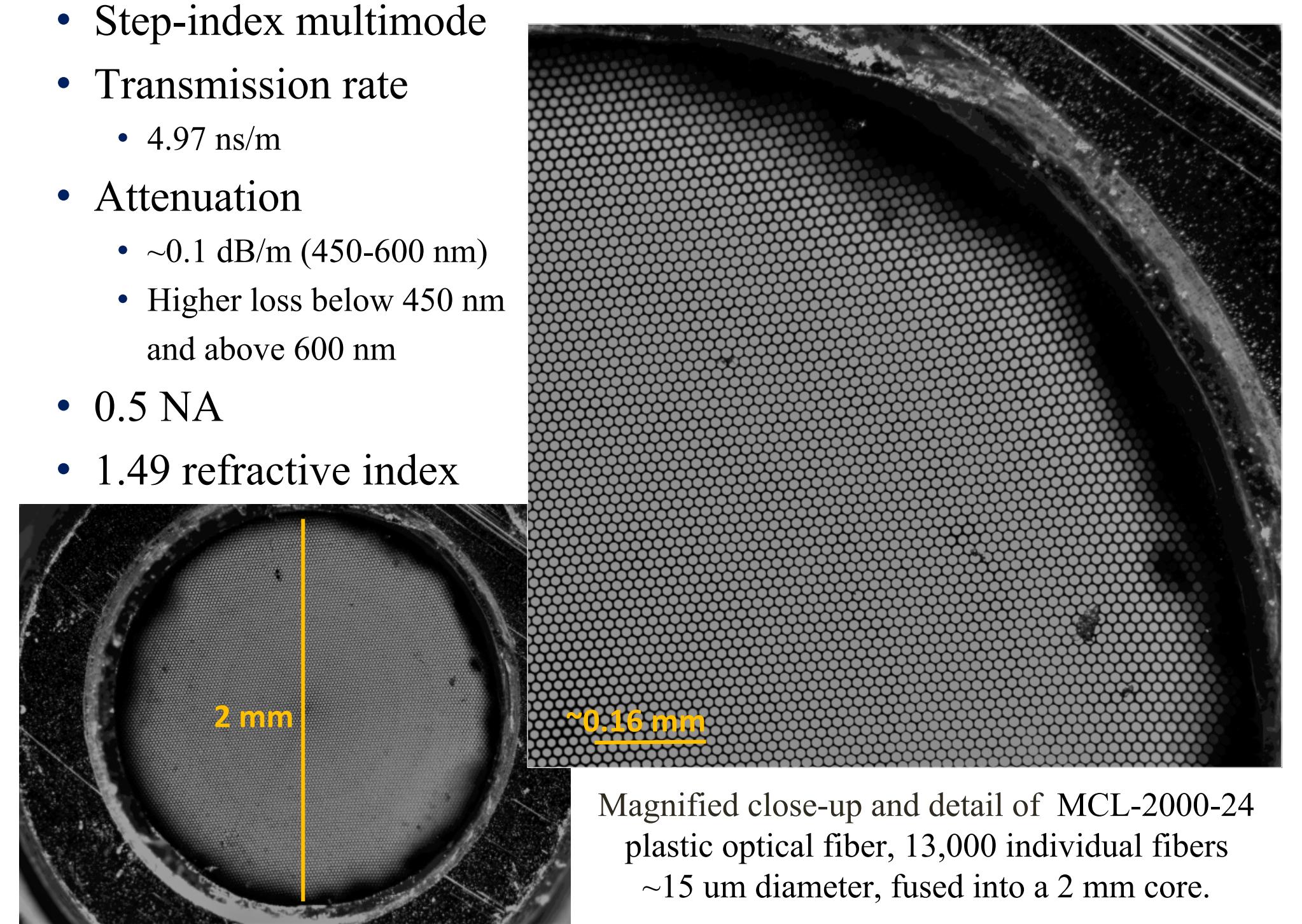
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- Transmission rate
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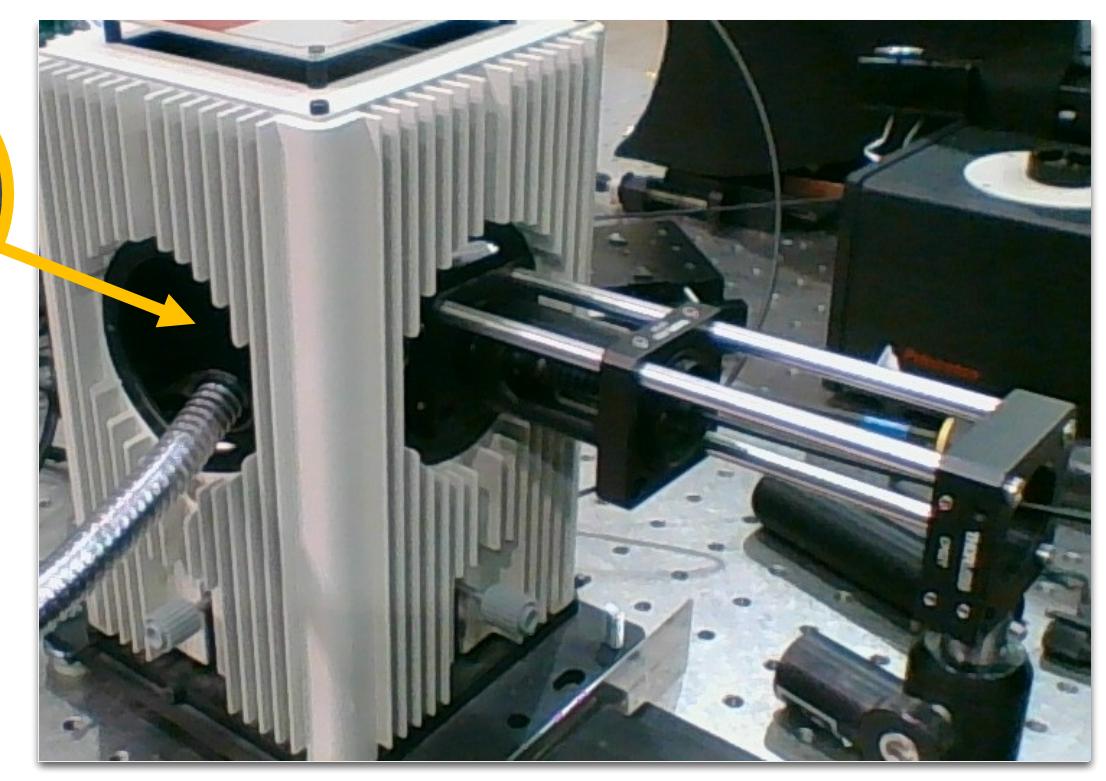


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Source Side

- ❖ Input sources

- Arc lamp, Xenon
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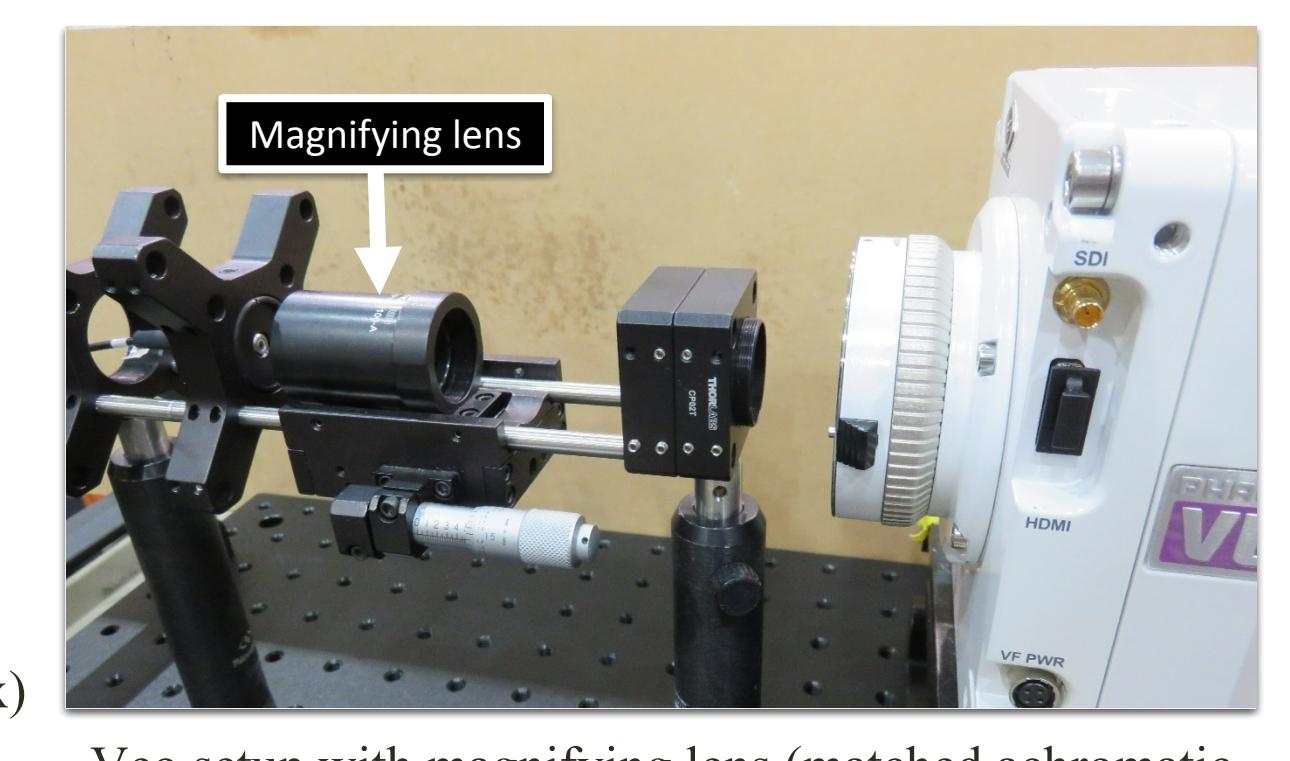


Arc lamp with focusing lens cage system. Detail of interior electrodes.

Sensor Side

- ❖ Focusing lenses

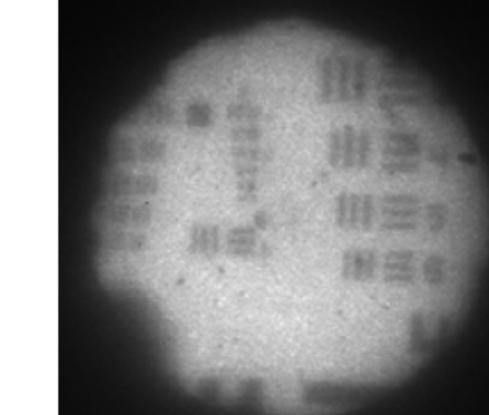
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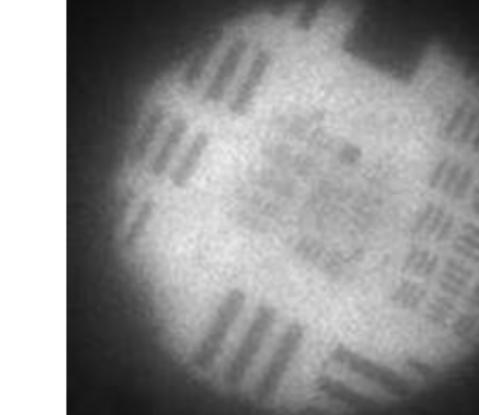
Bench Testing

Small Lens



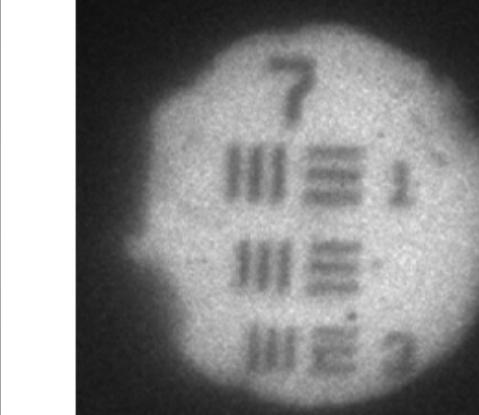
Resolution (6-1 element):
8 μm , 64 lp/mm
FOV: 0.3 mm

Wide Angle



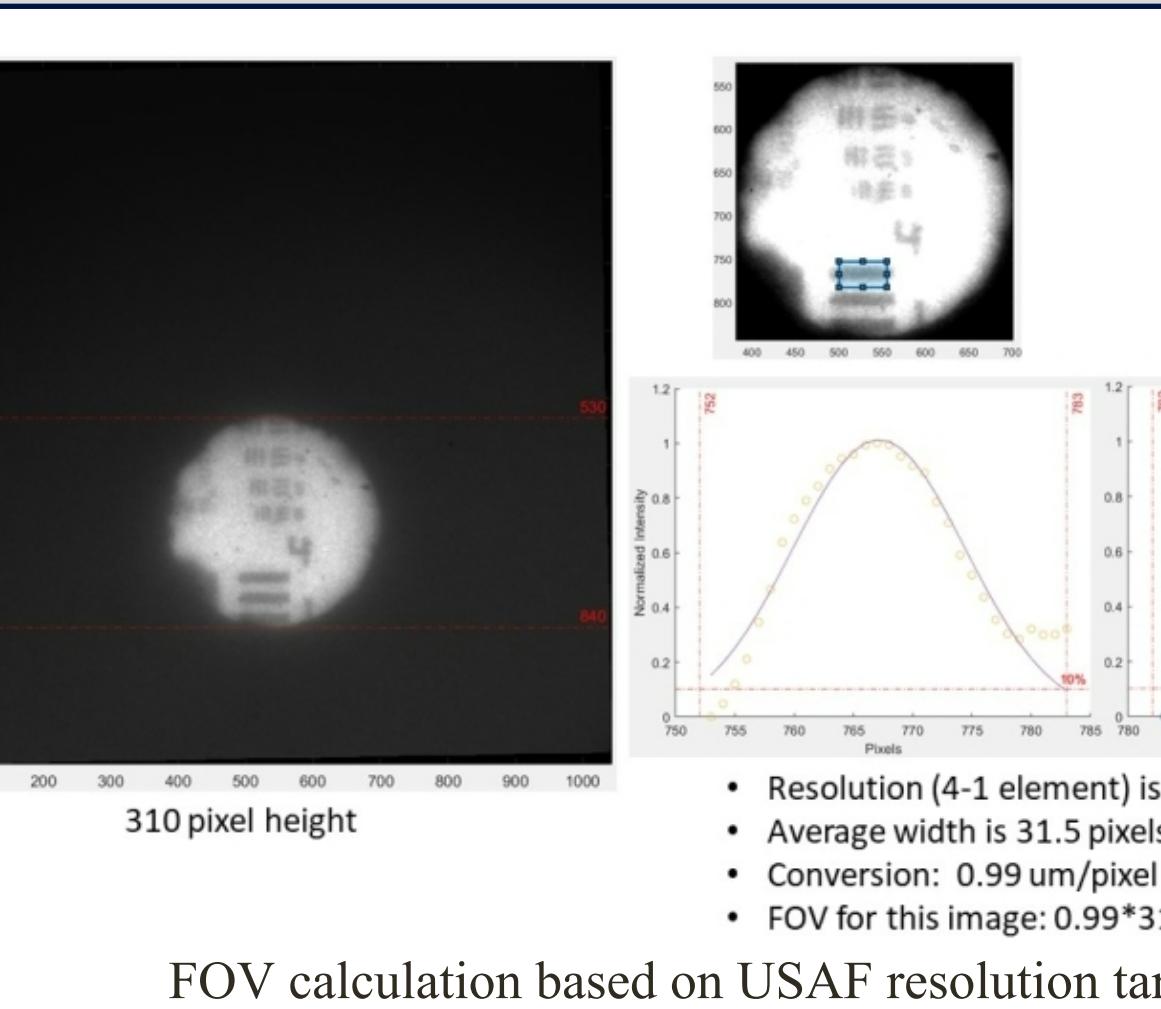
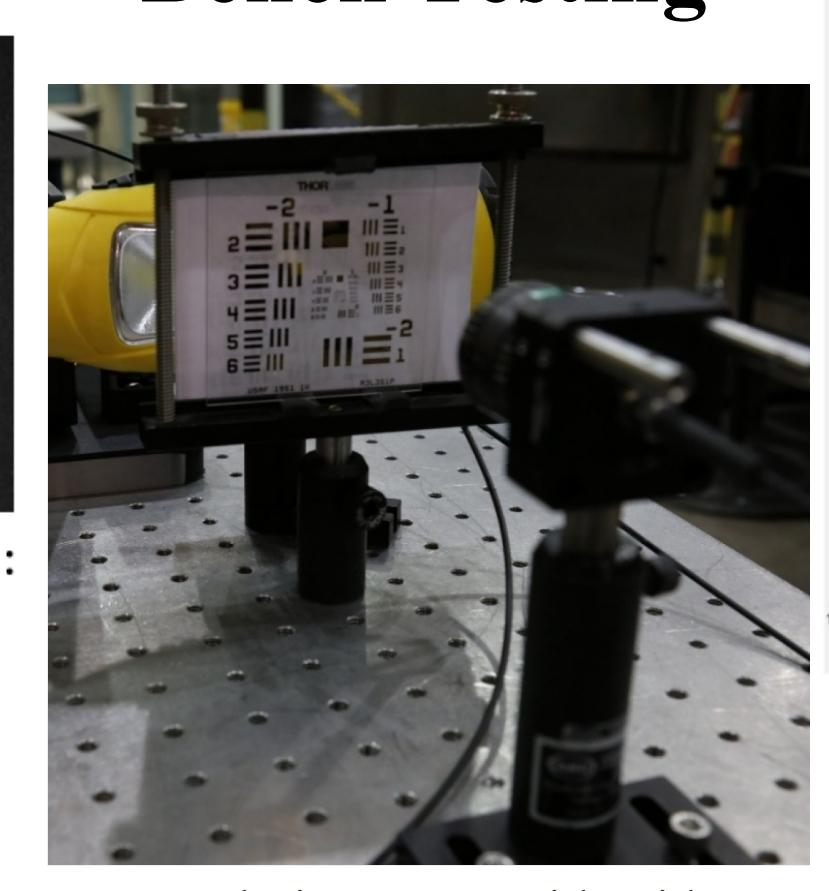
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Gate: 300 μs

Objective



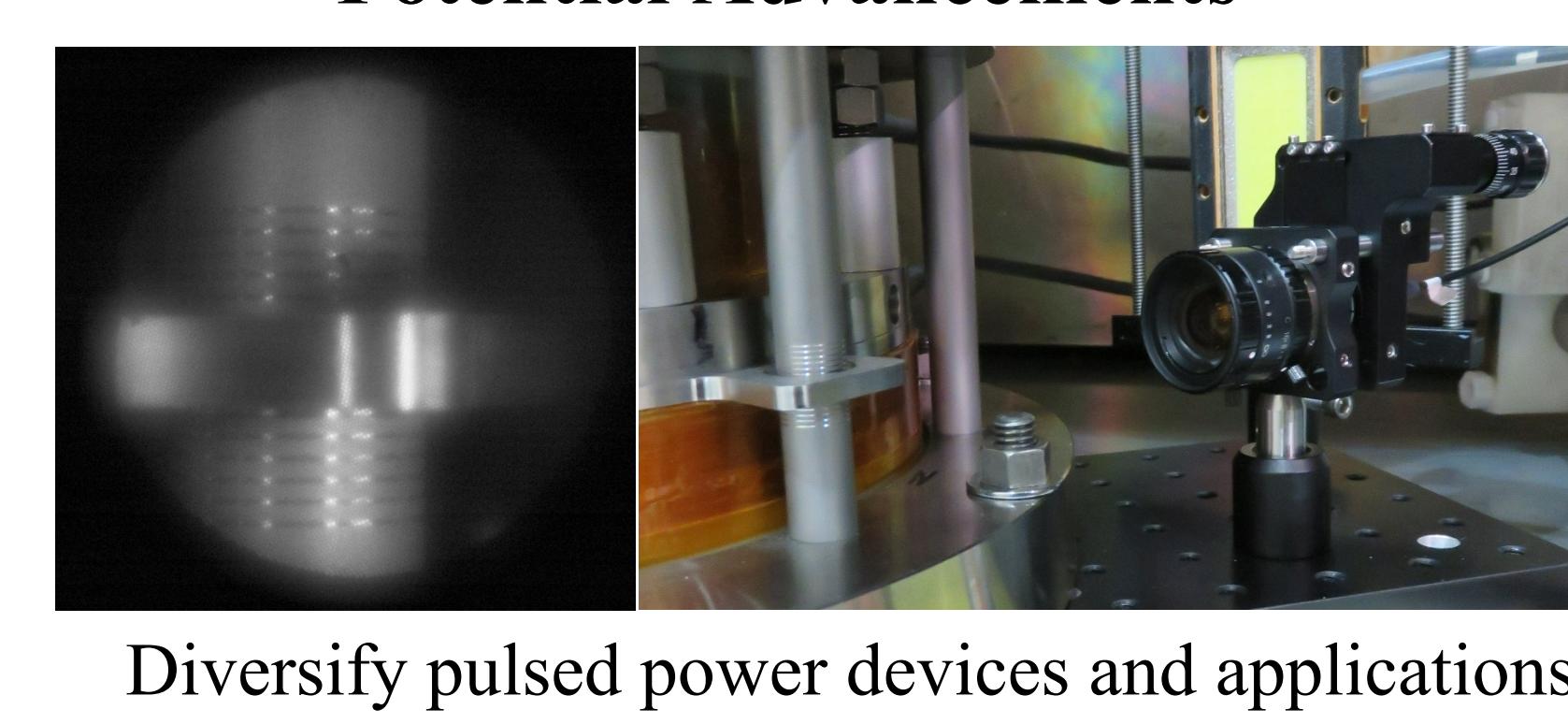
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Resolution target with wide angle lens and LED



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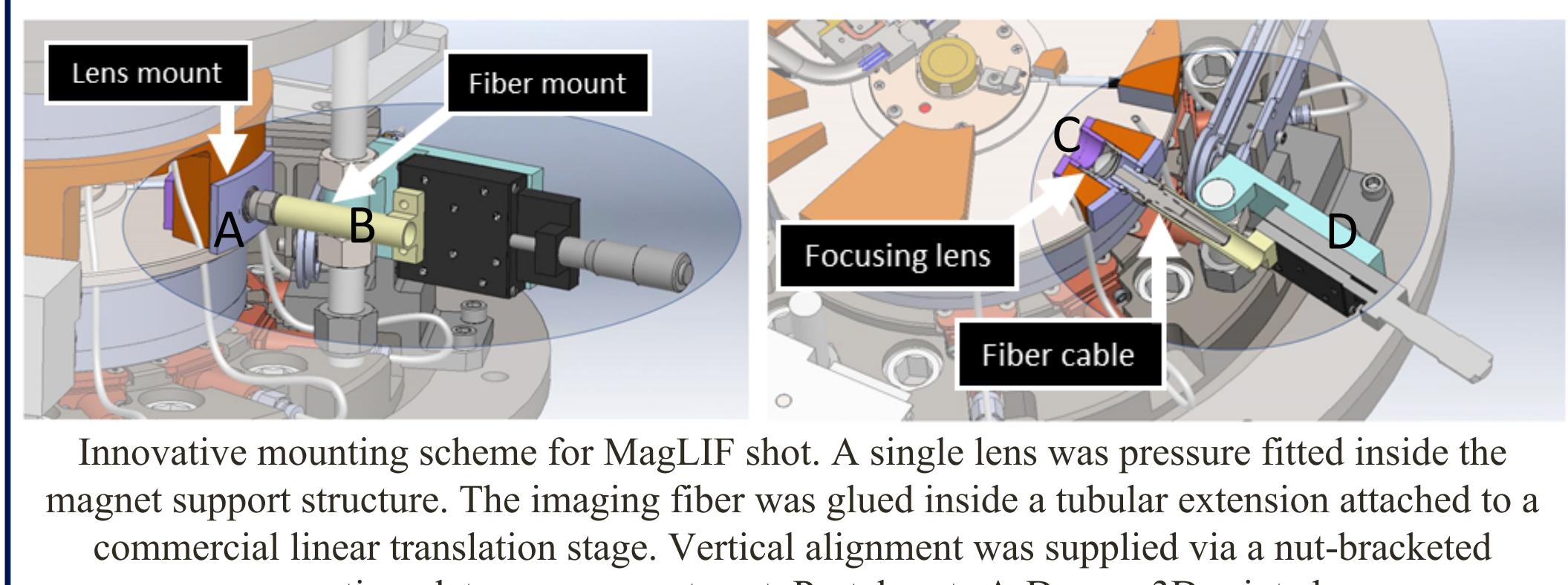
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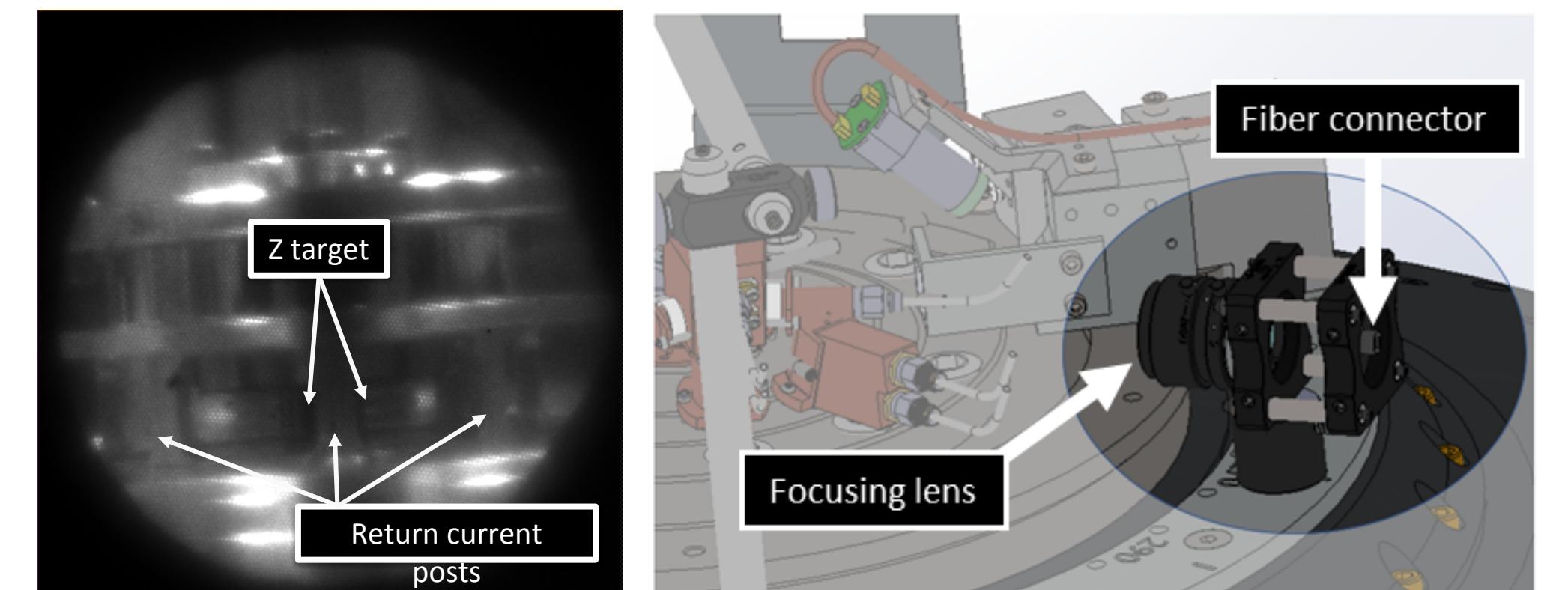
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Innovative mounting scheme for MagLIF shot. A single lens was pressure fitted inside the magnet support structure. The imaging fiber was glued inside a tubular extension attached to a commercial linear translation stage. Vertical alignment was supplied via a nut-bracketed mounting plate on a support post. Pastel parts A-D were 3D printed.

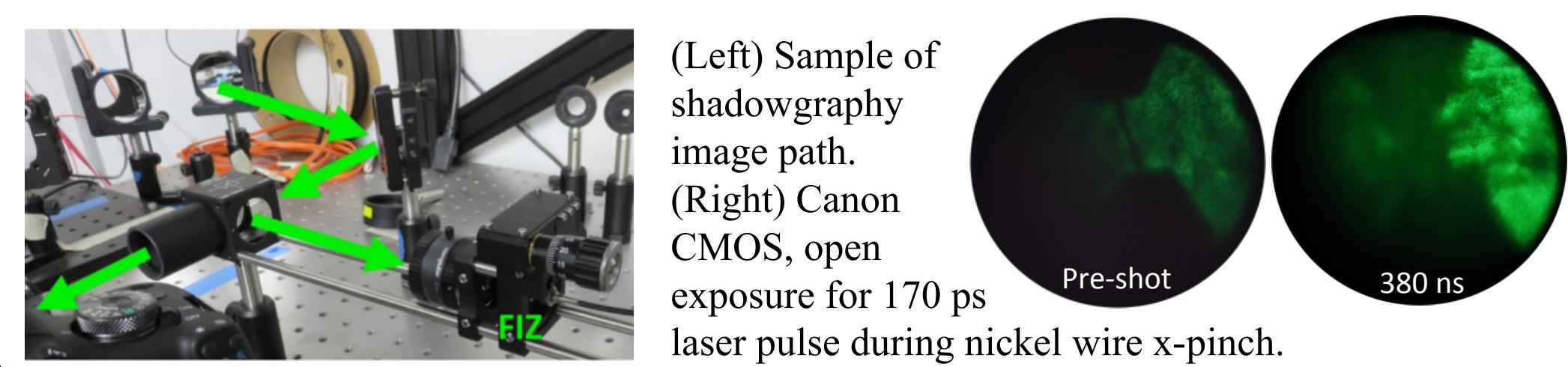
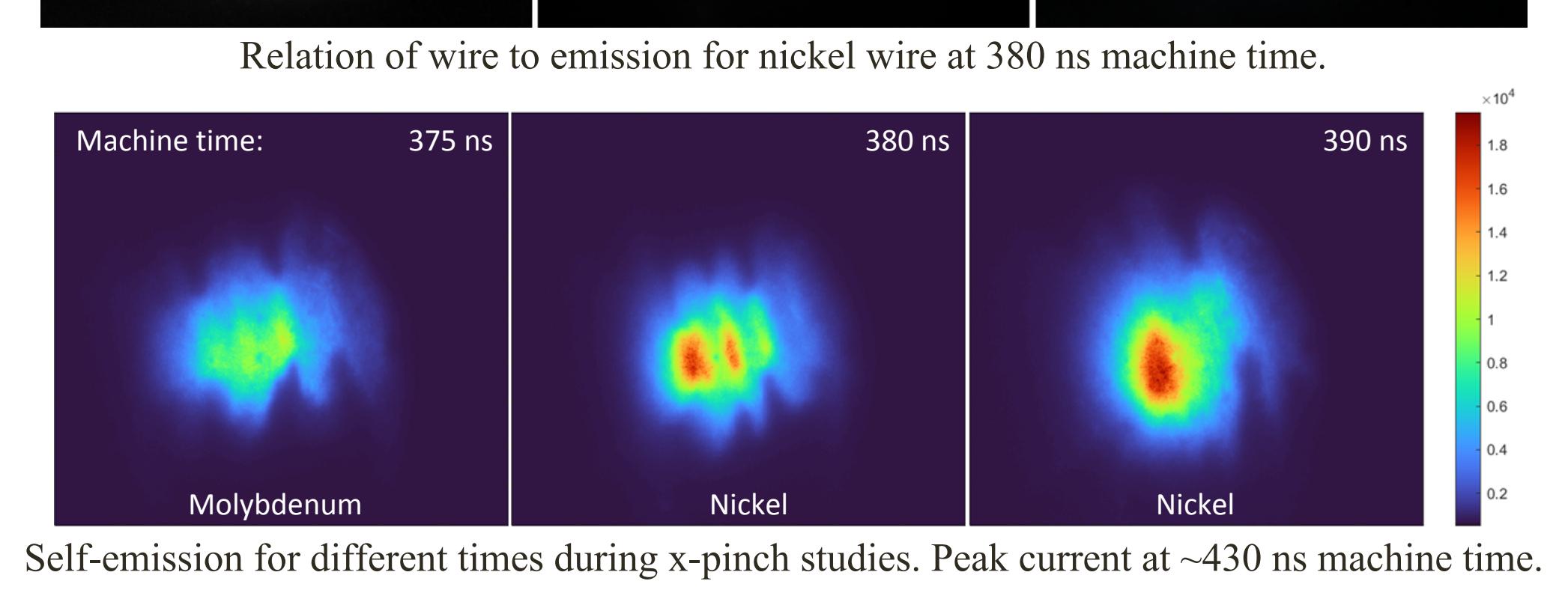
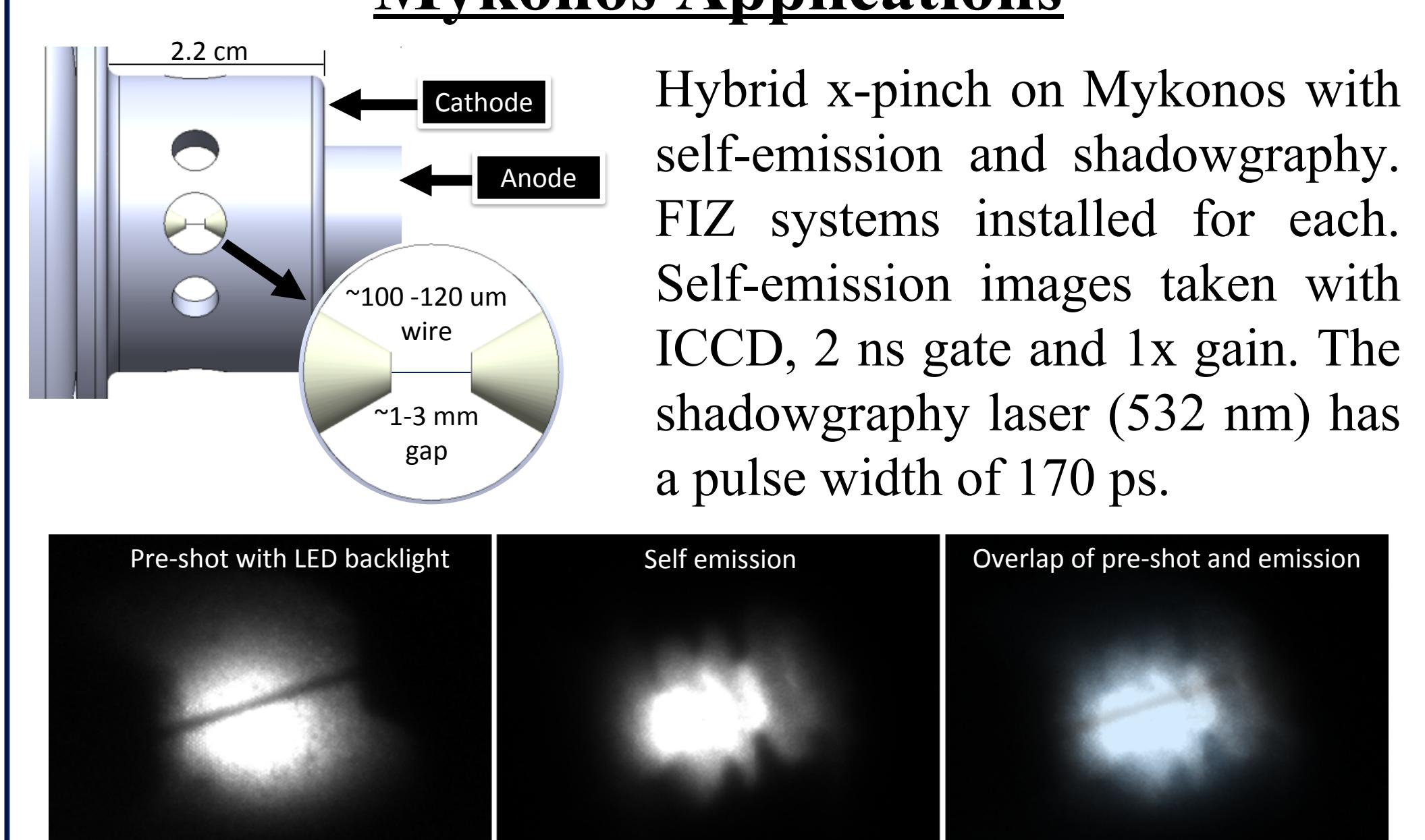


FOV test image with commercial lens configuration on the aperture ring.

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High resolution fiber imaging for pulsed power experiments

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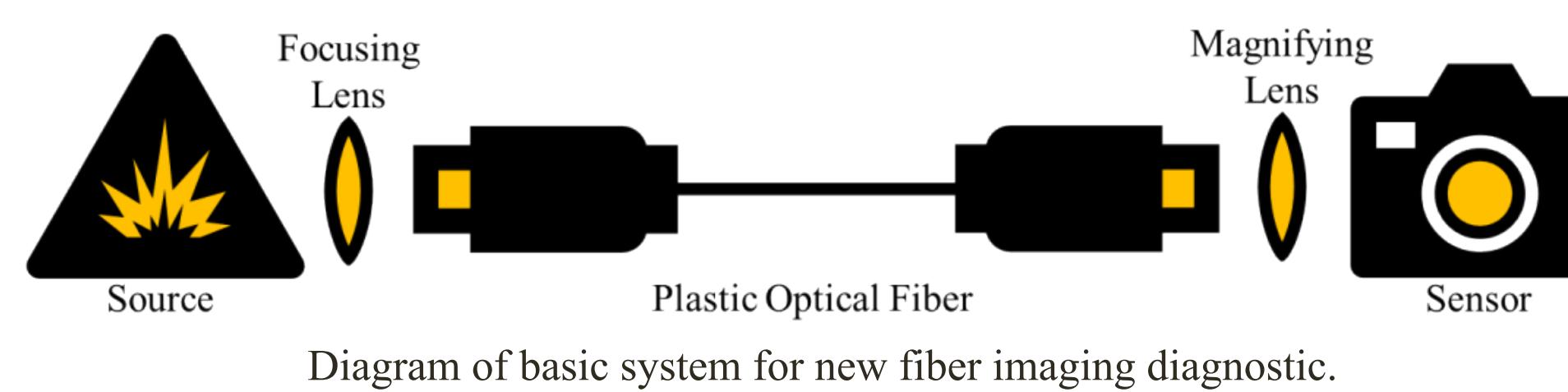
(a) Sandia National Laboratories, (b) University of New Mexico



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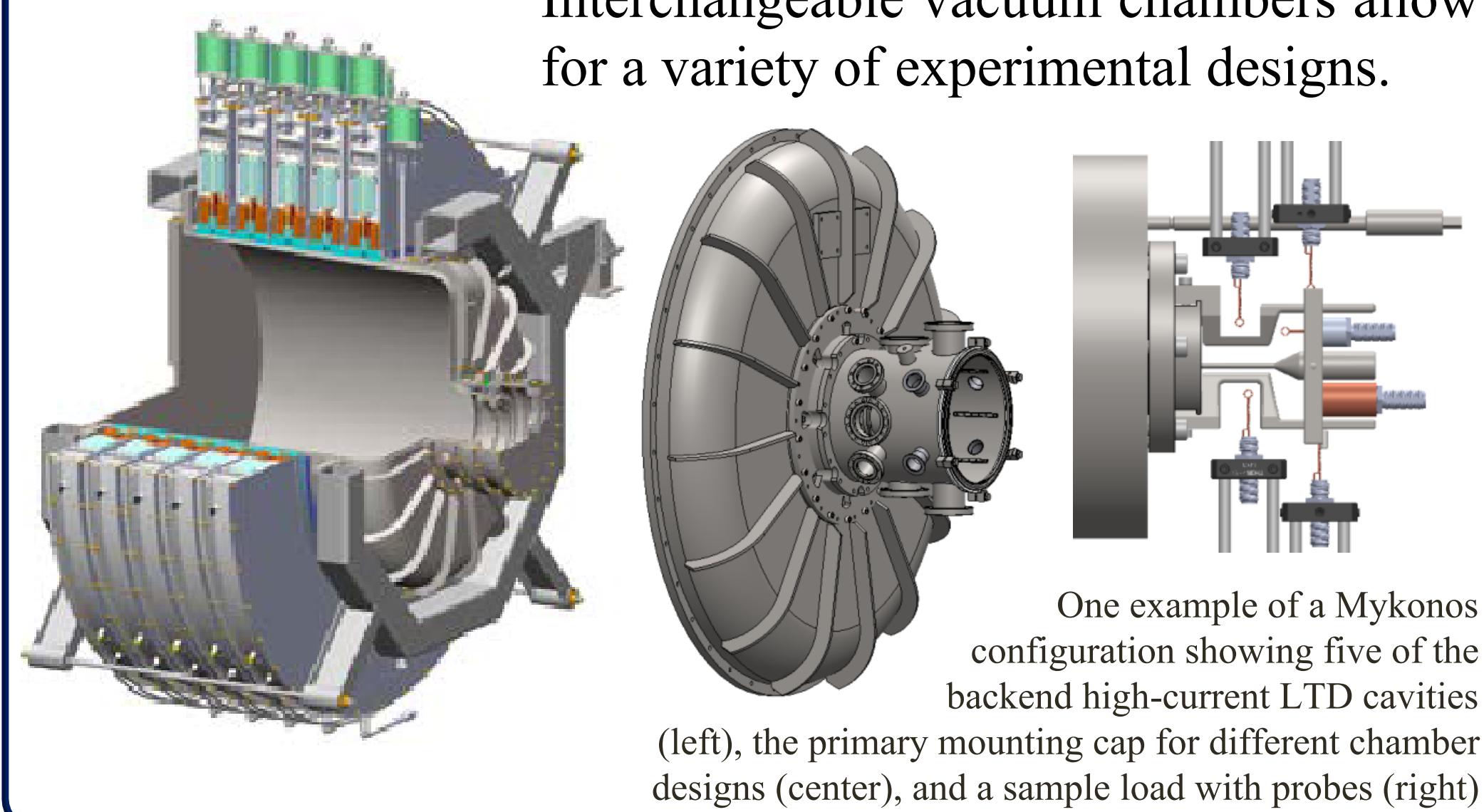
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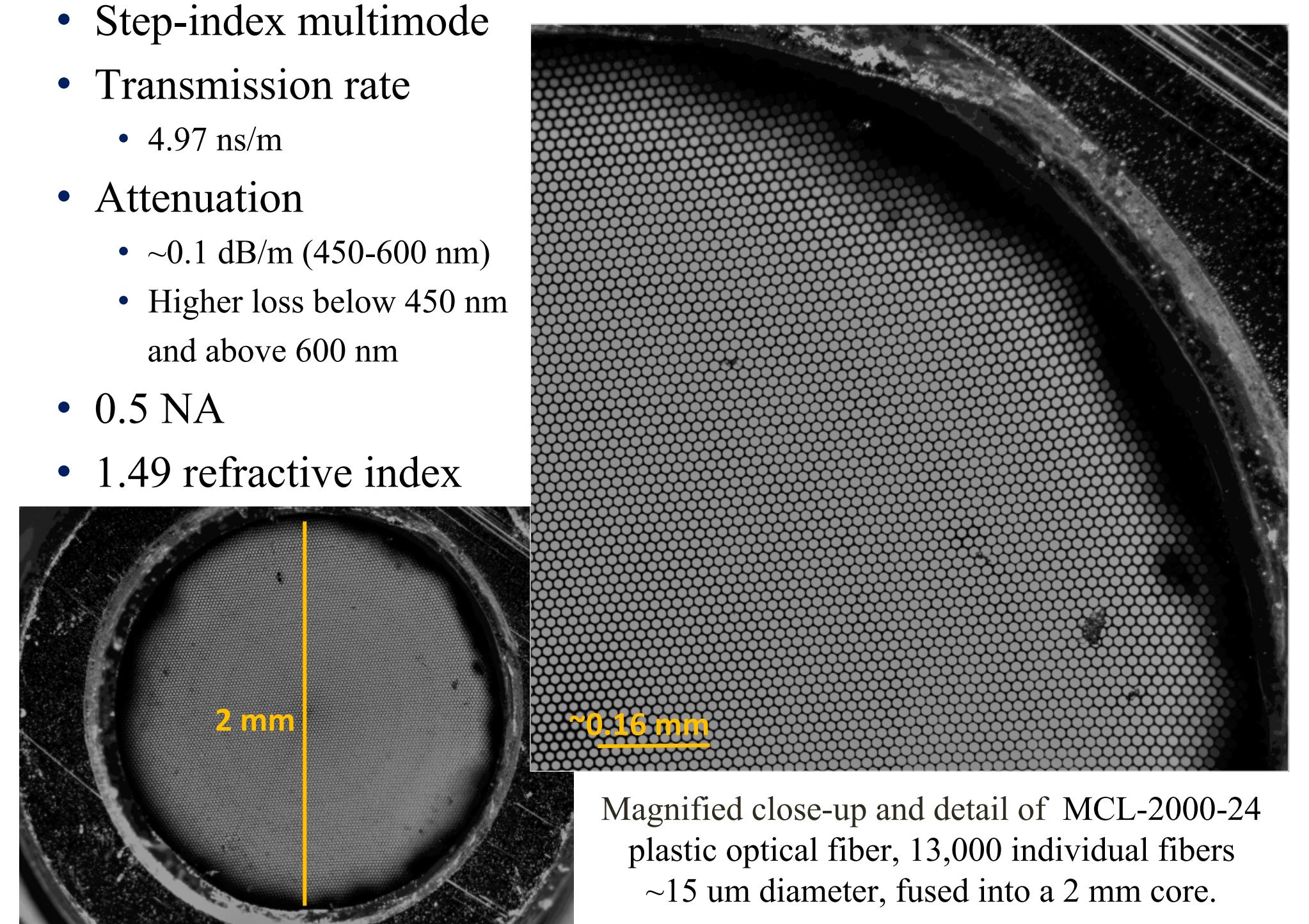
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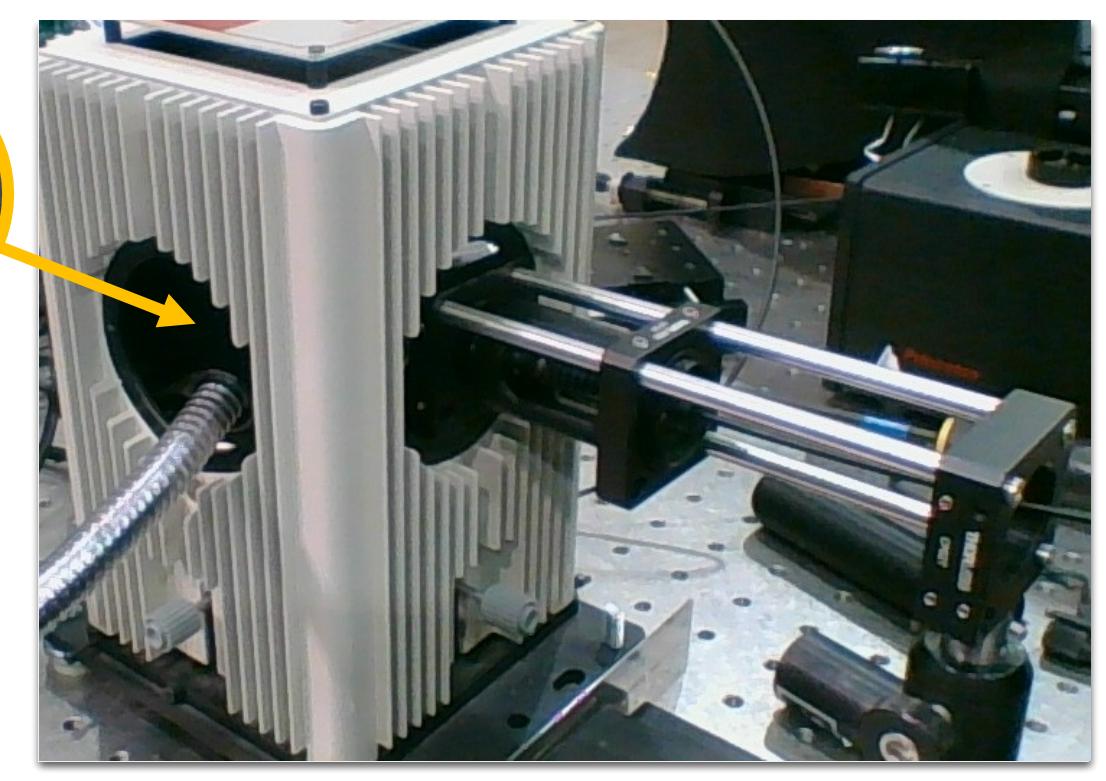


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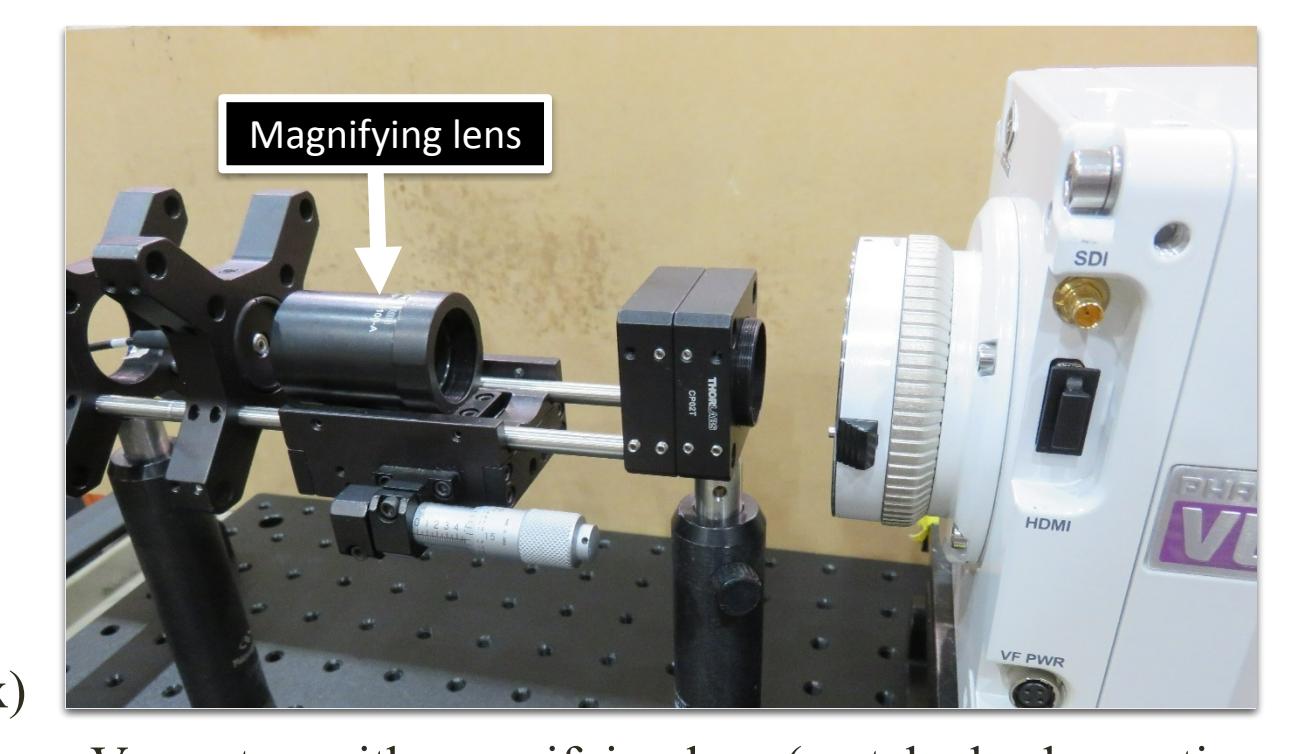


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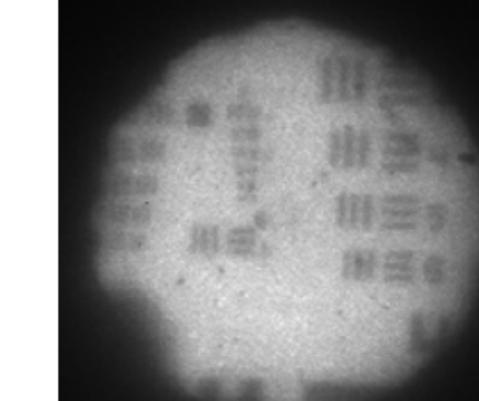
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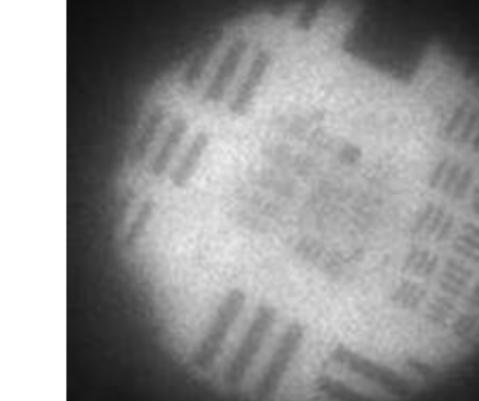
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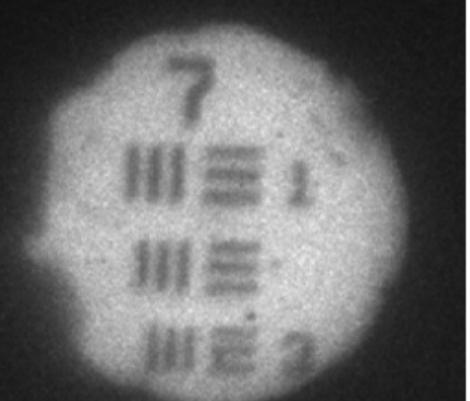
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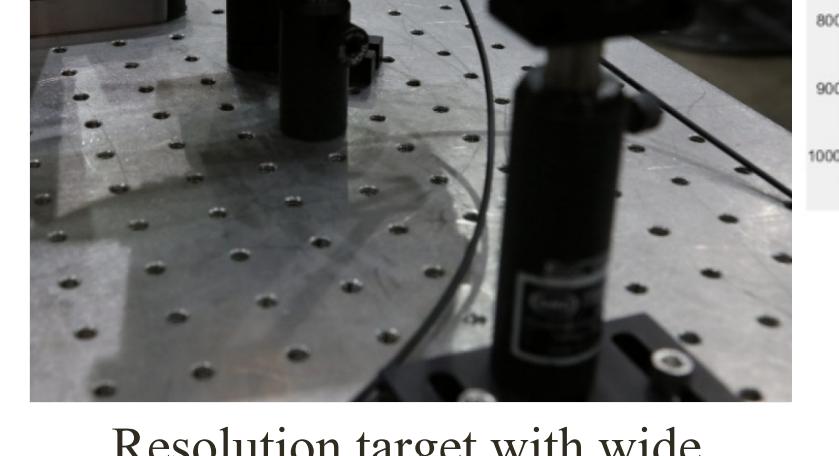


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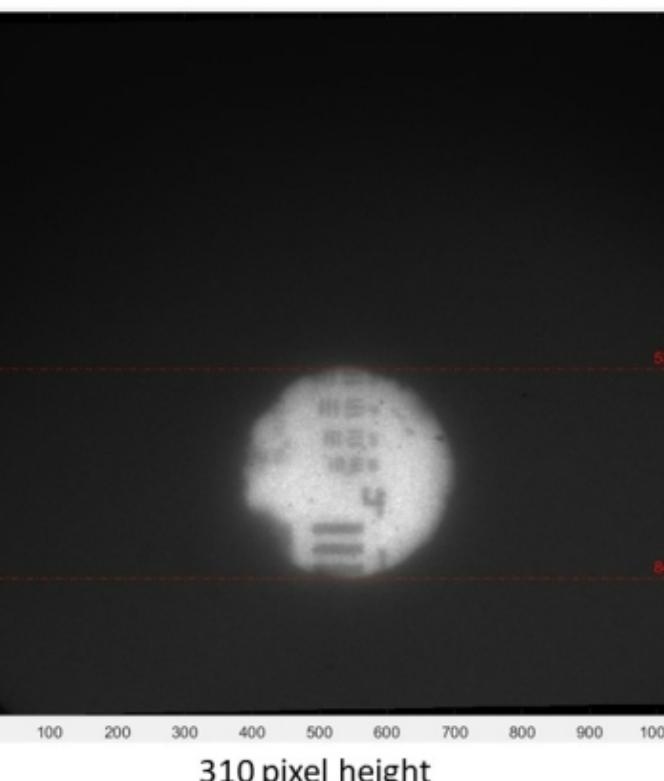


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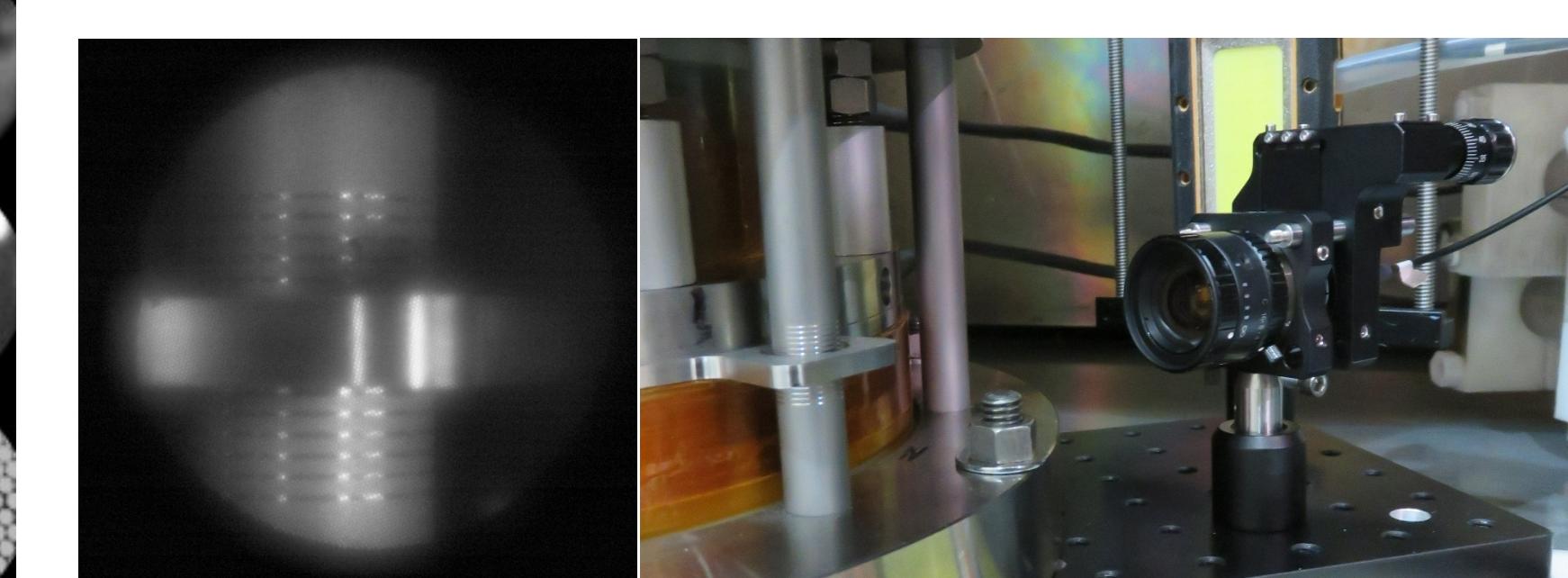
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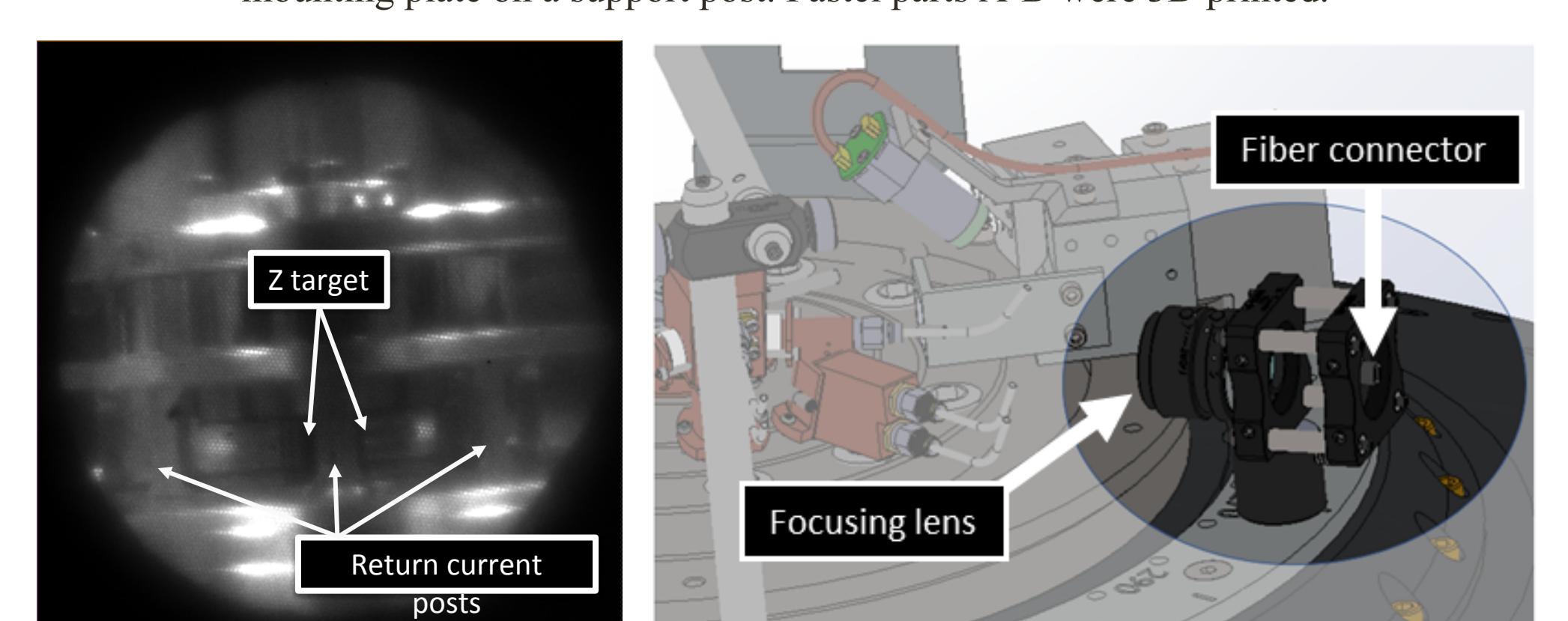
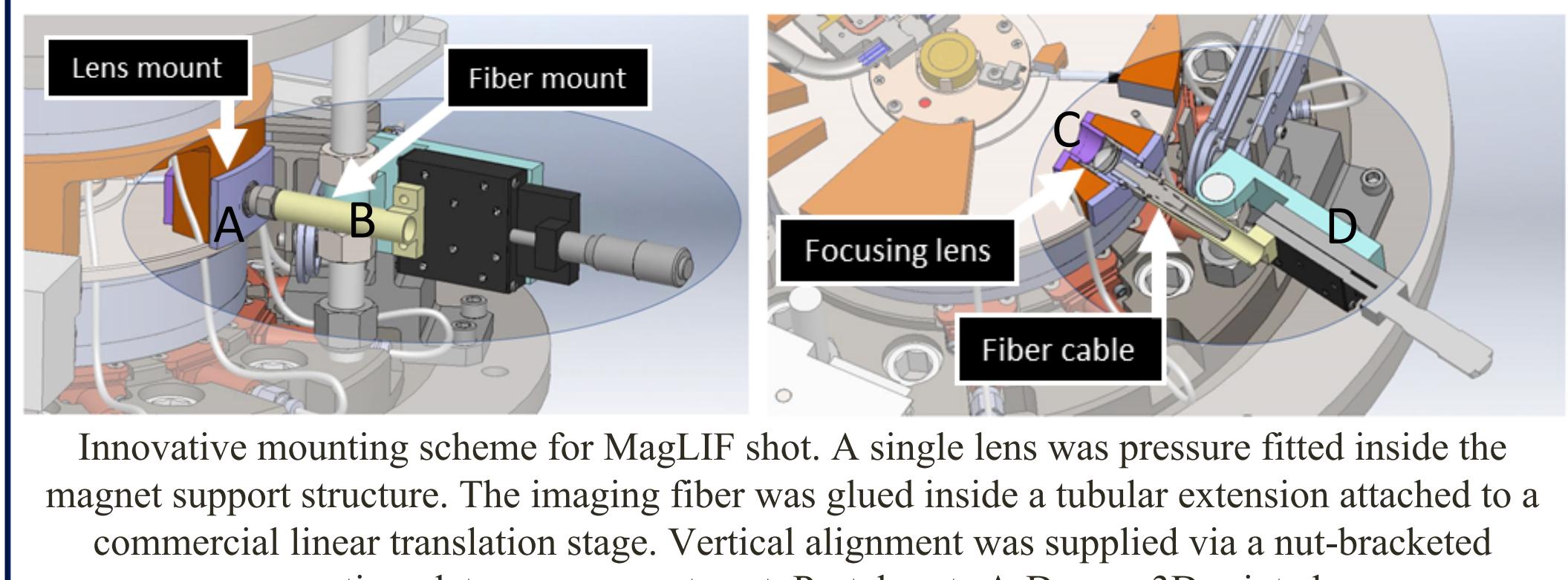
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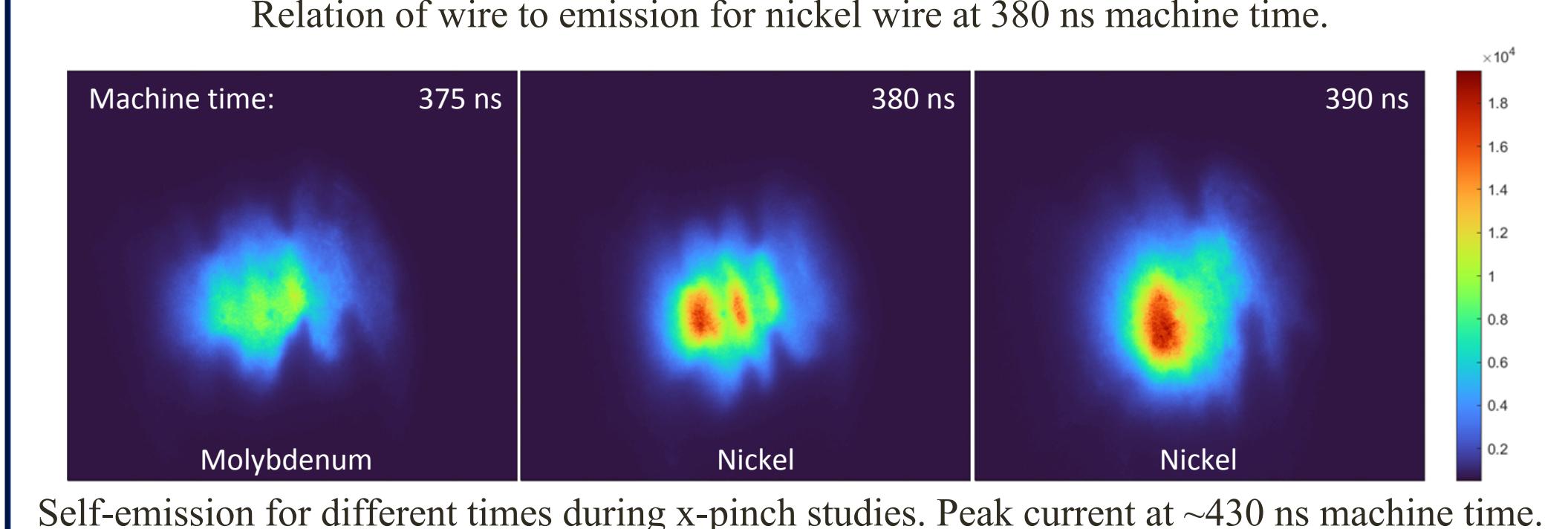
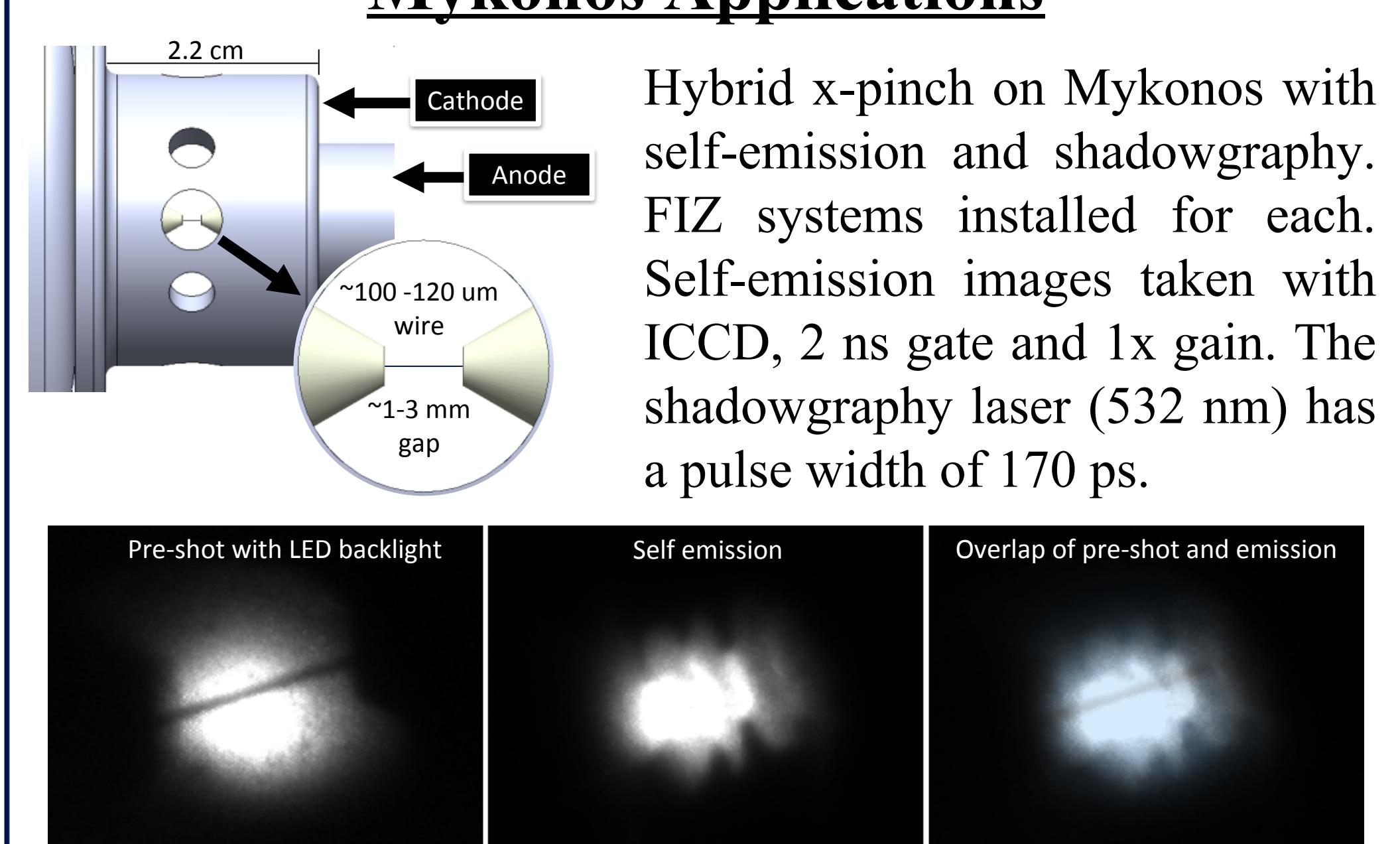


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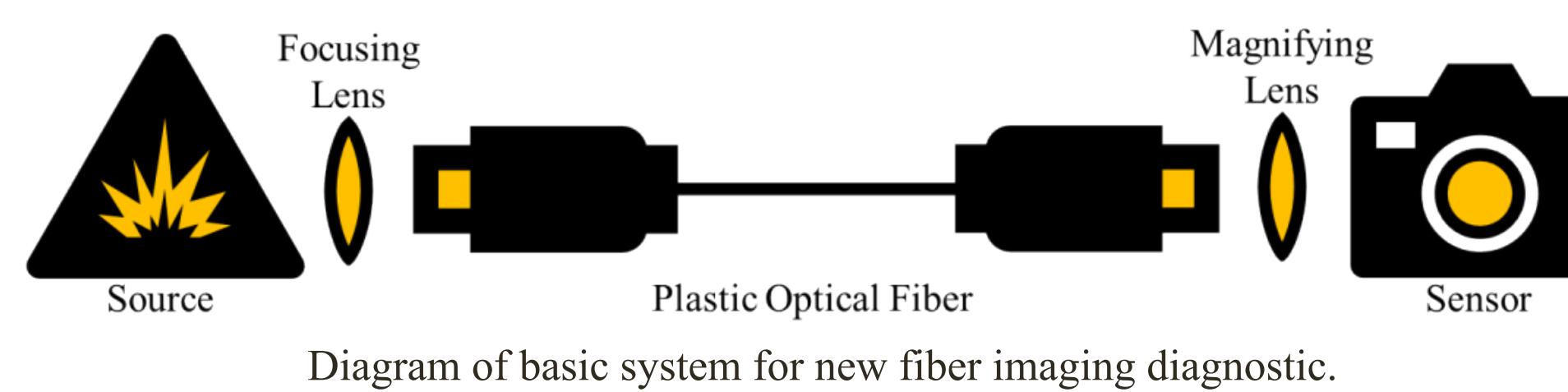
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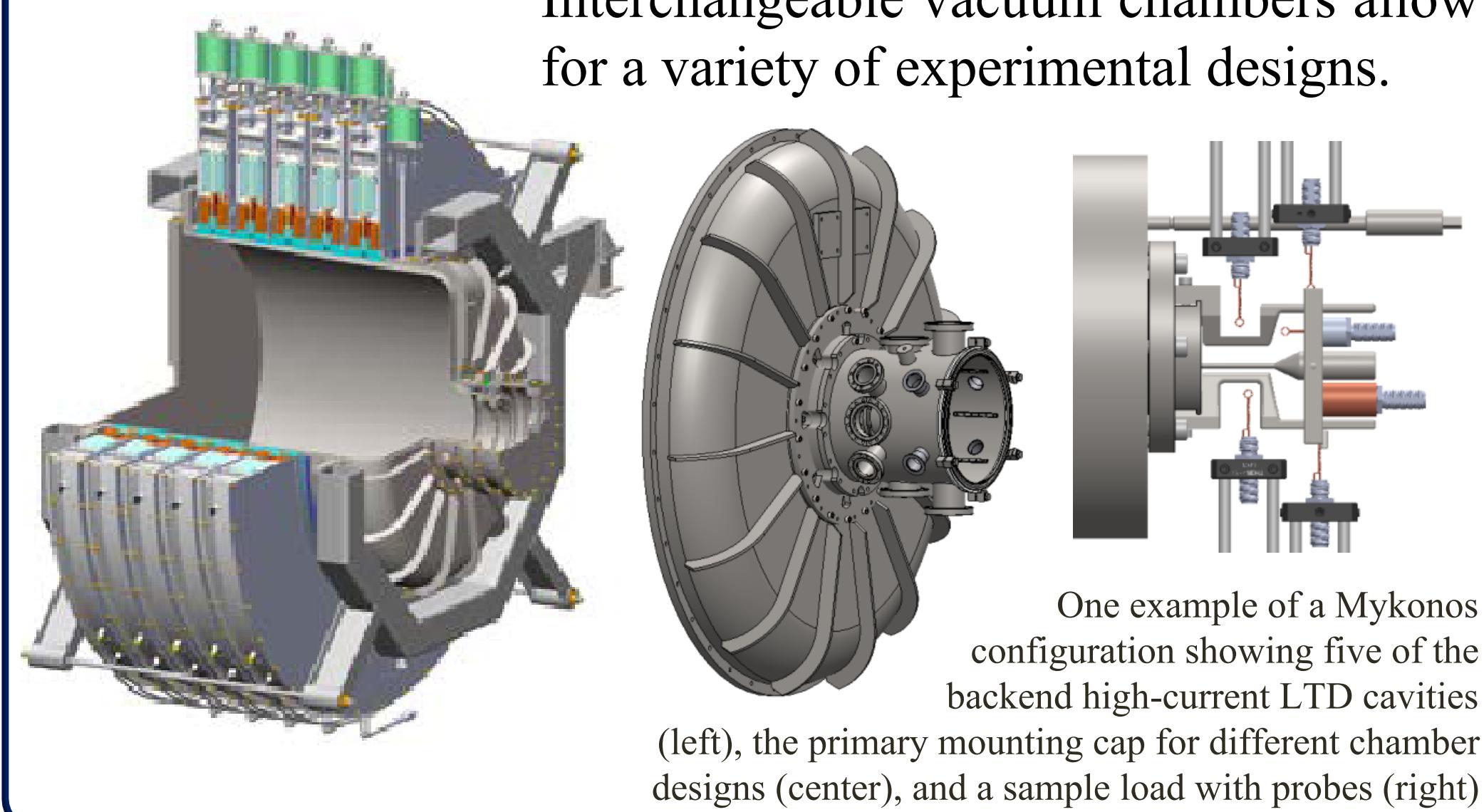
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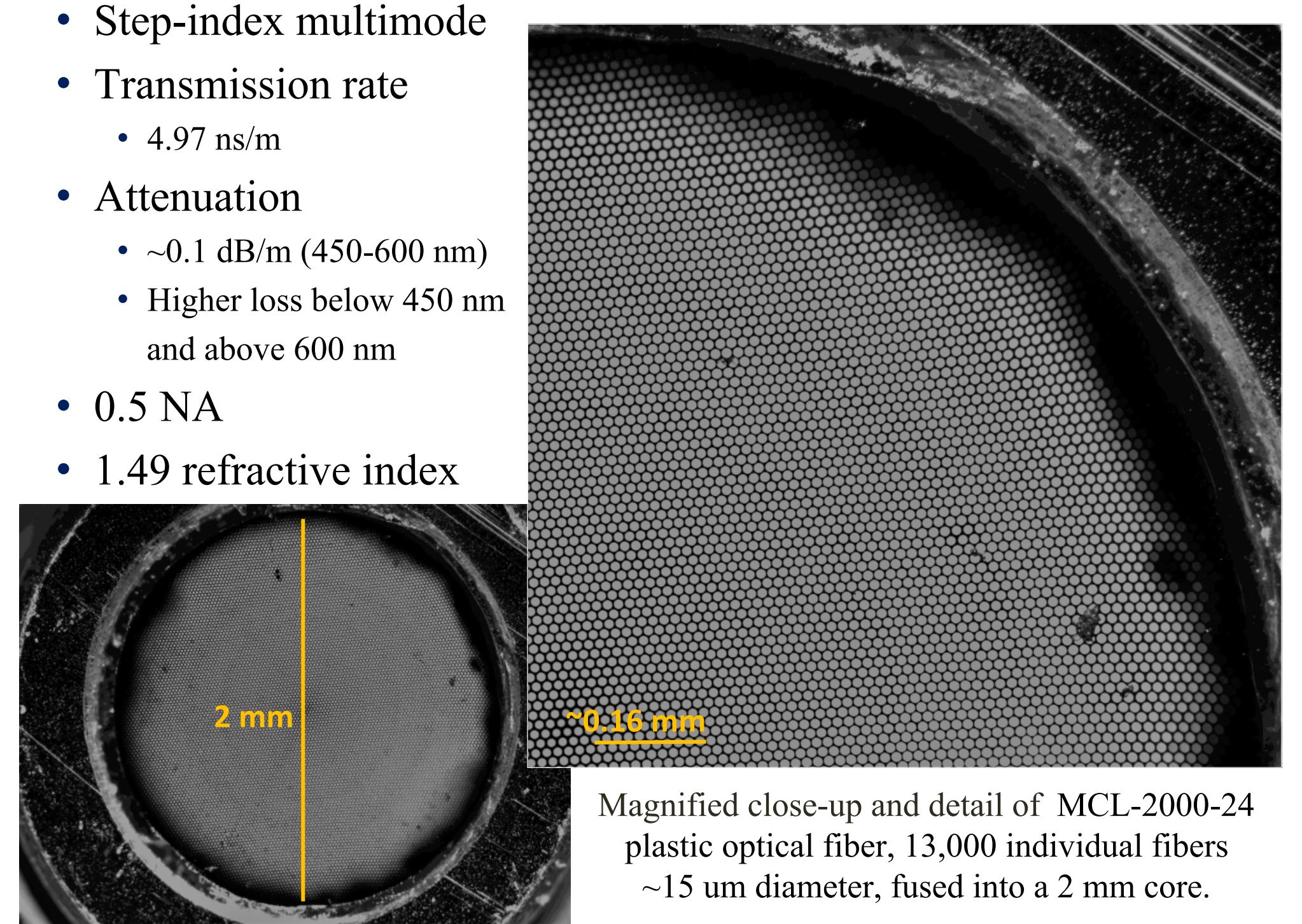
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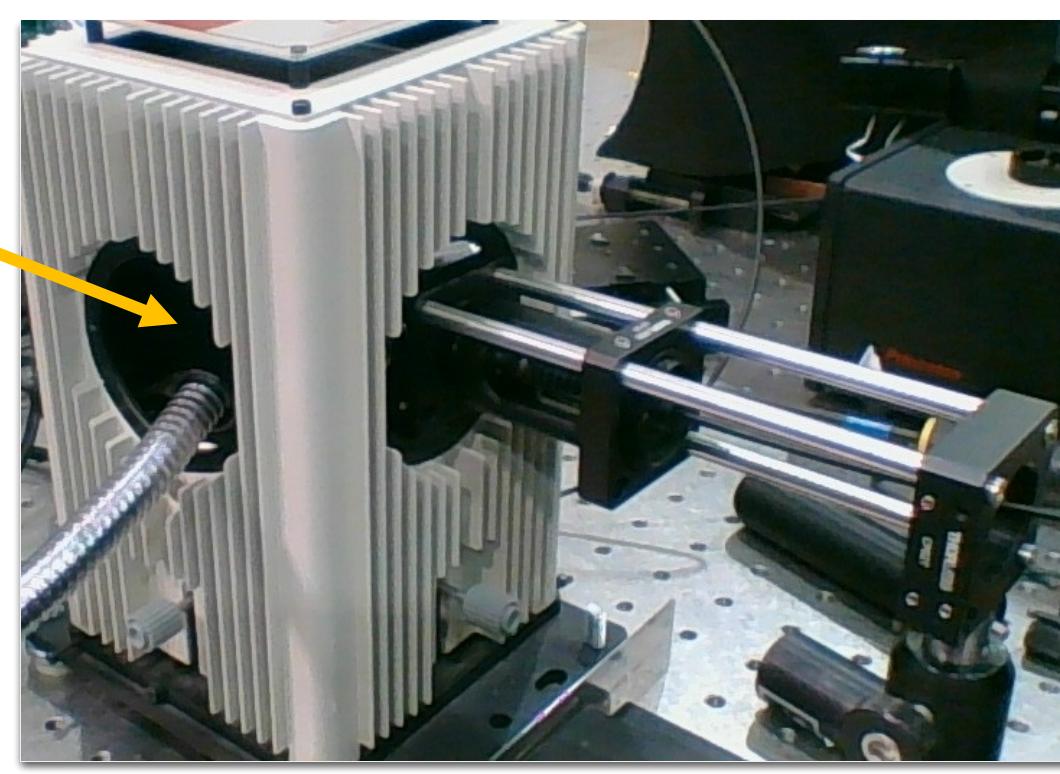


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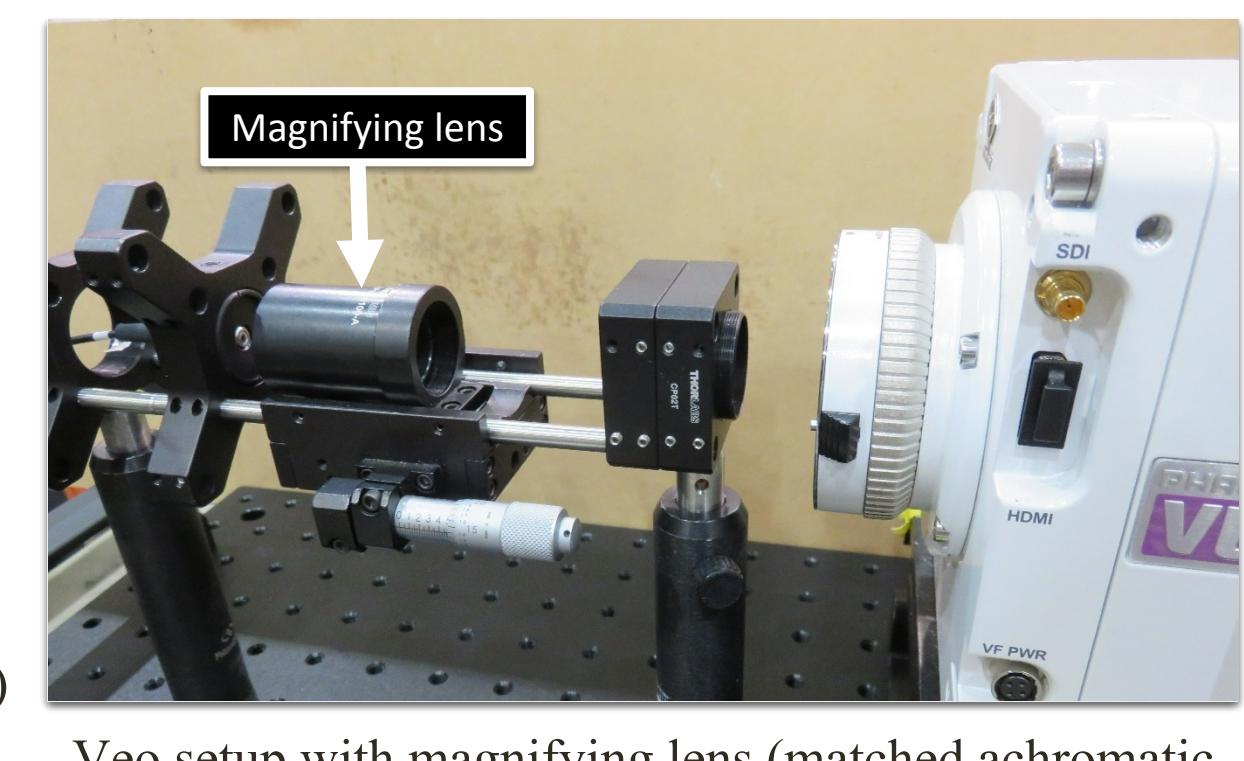


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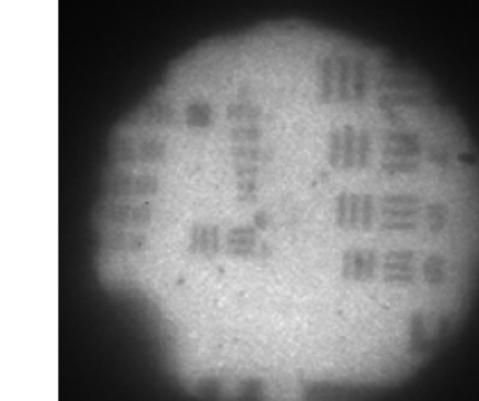
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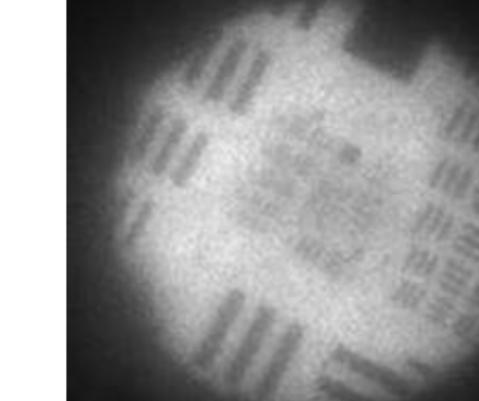
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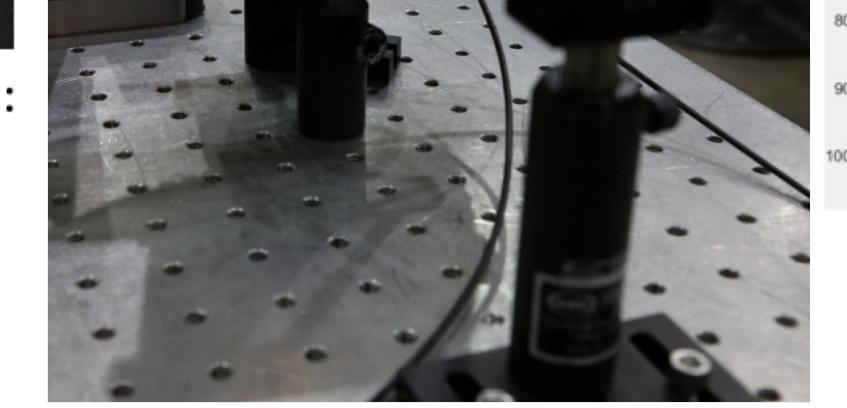


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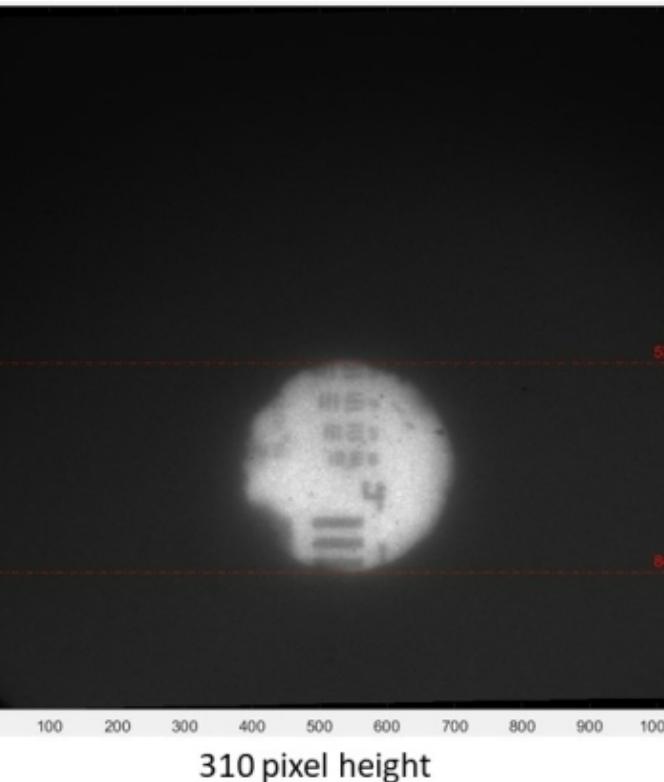


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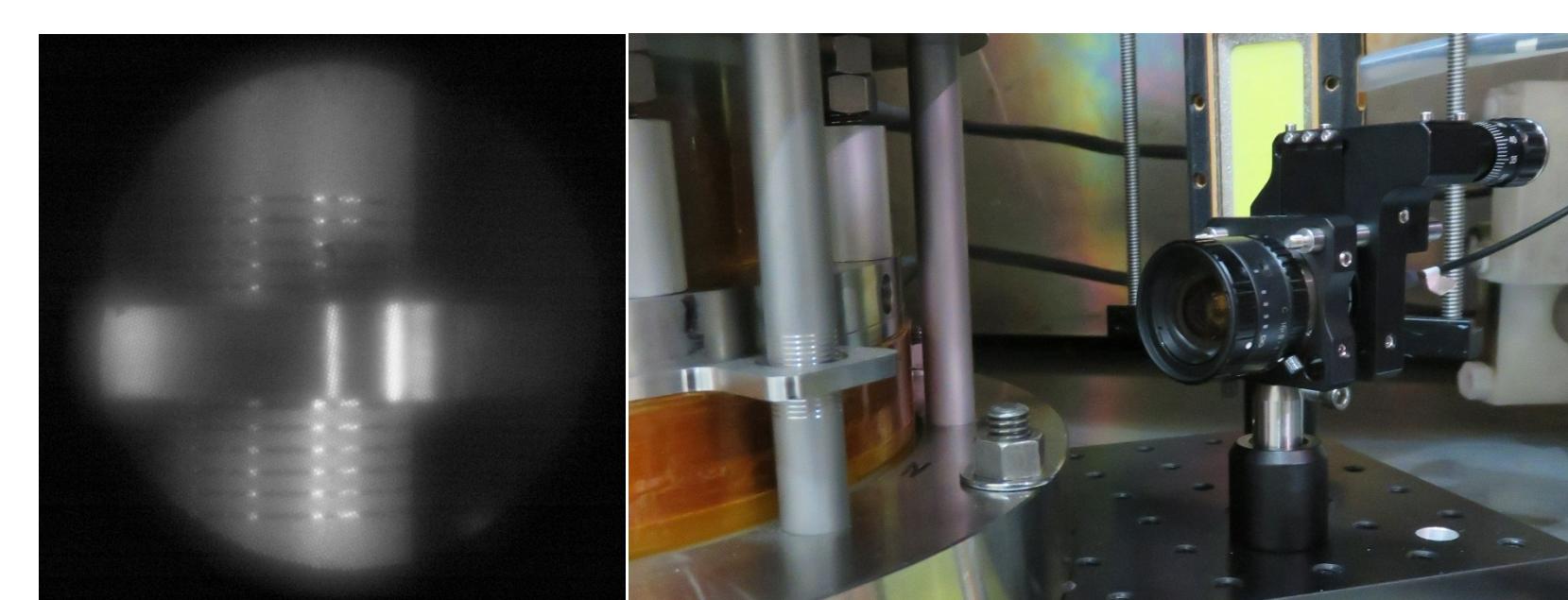
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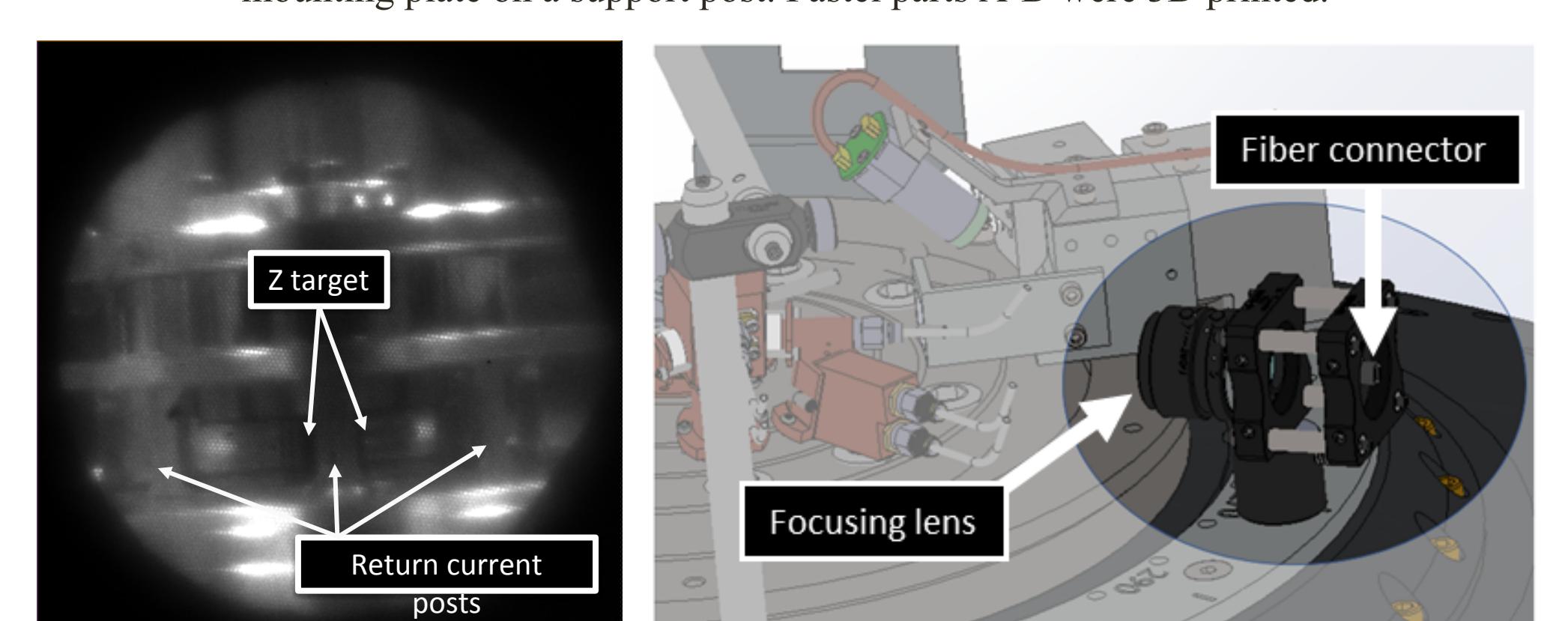
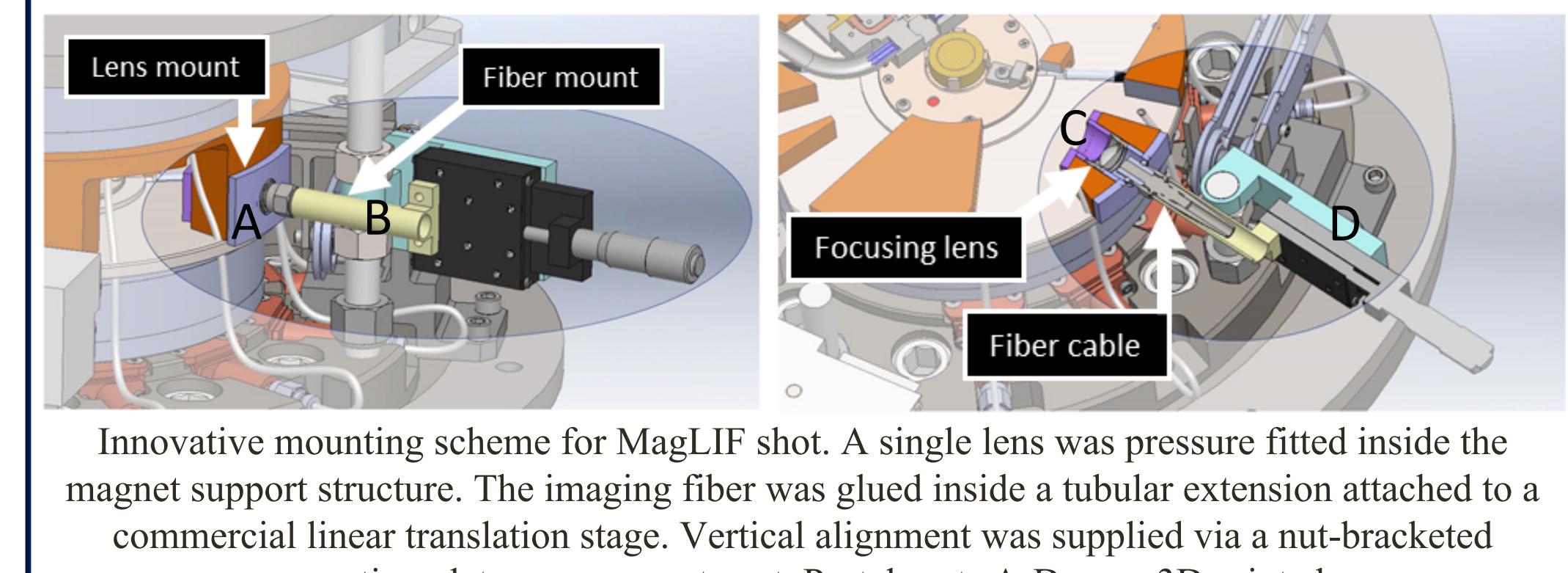
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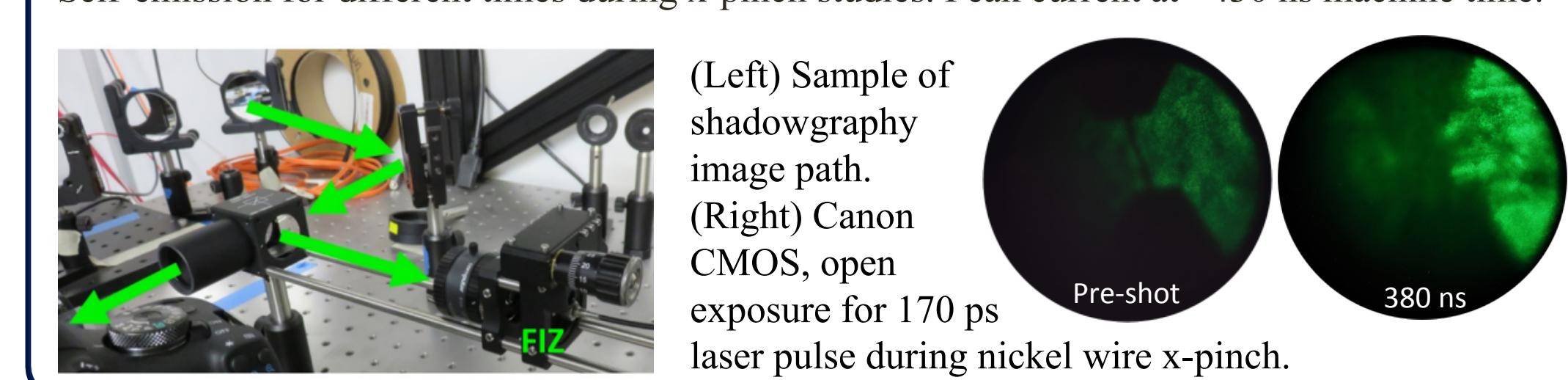
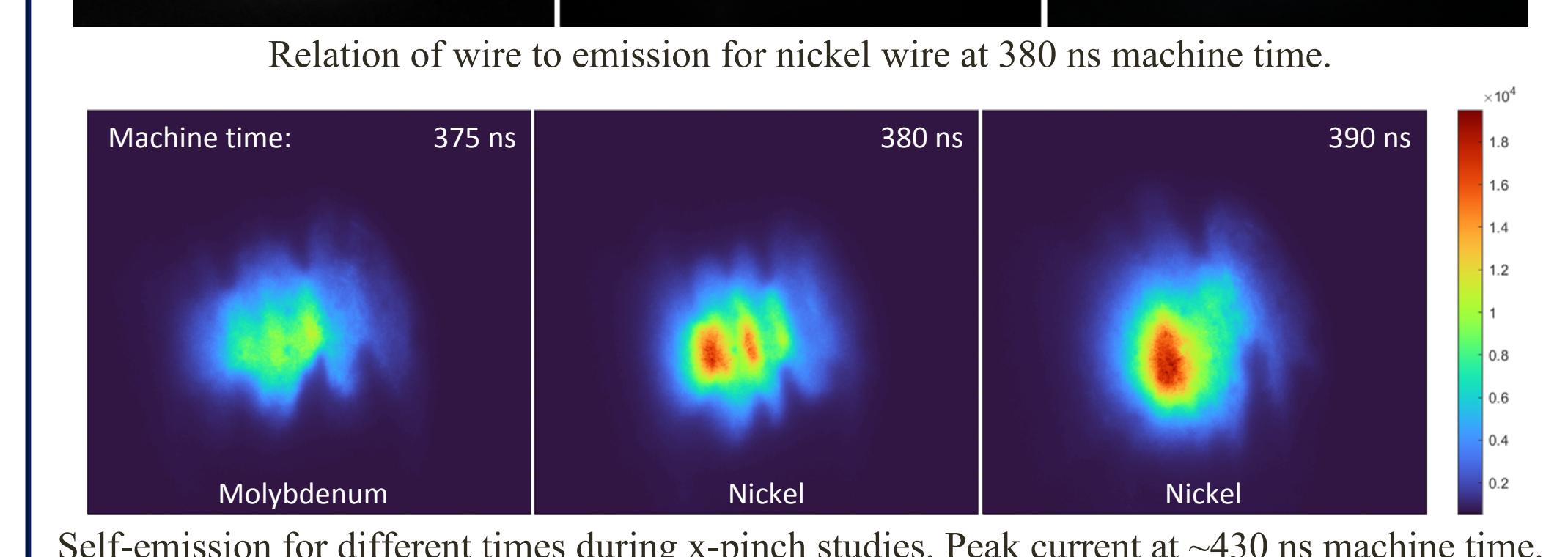
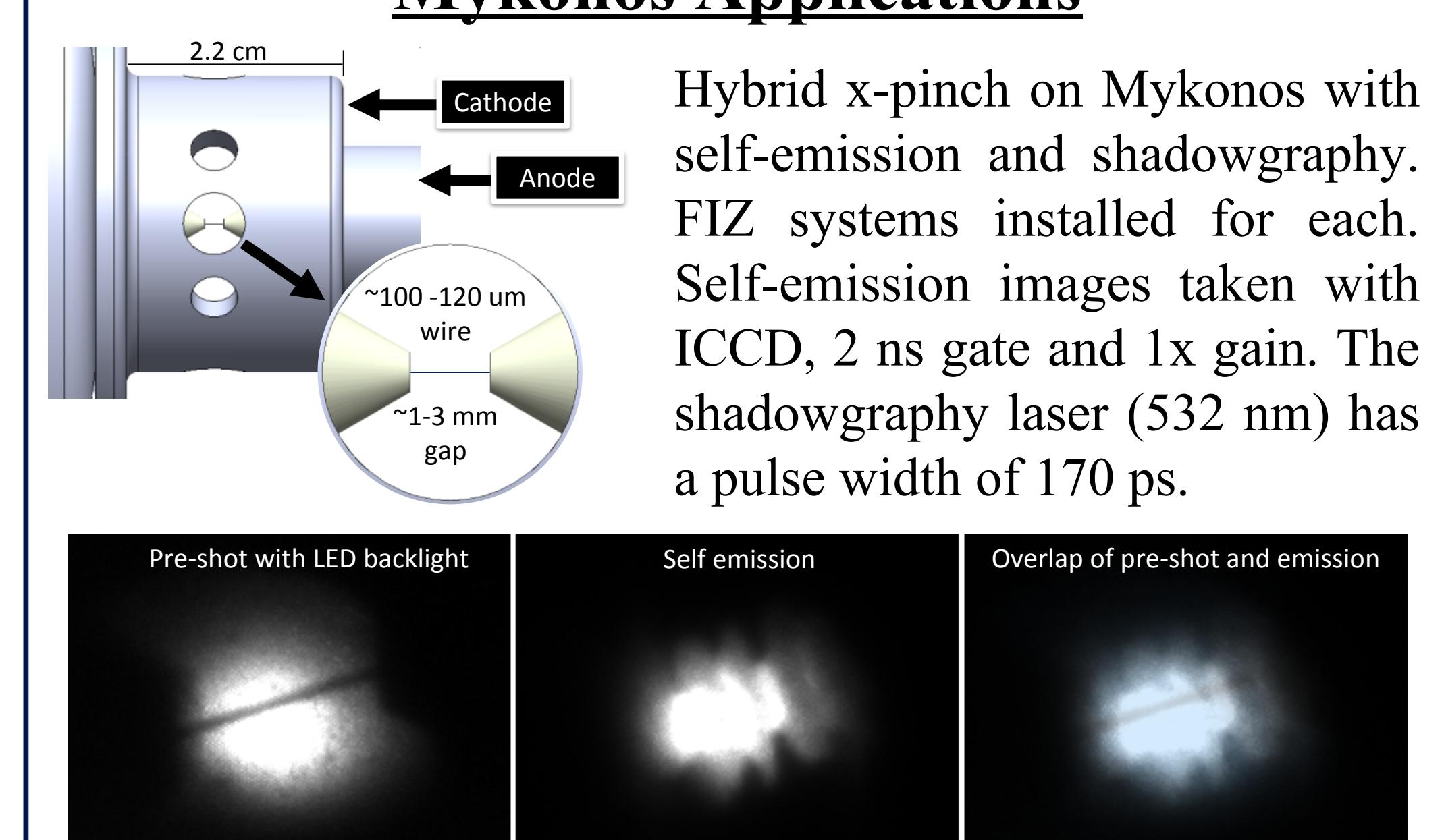


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High resolution fiber imaging for pulsed power experiments

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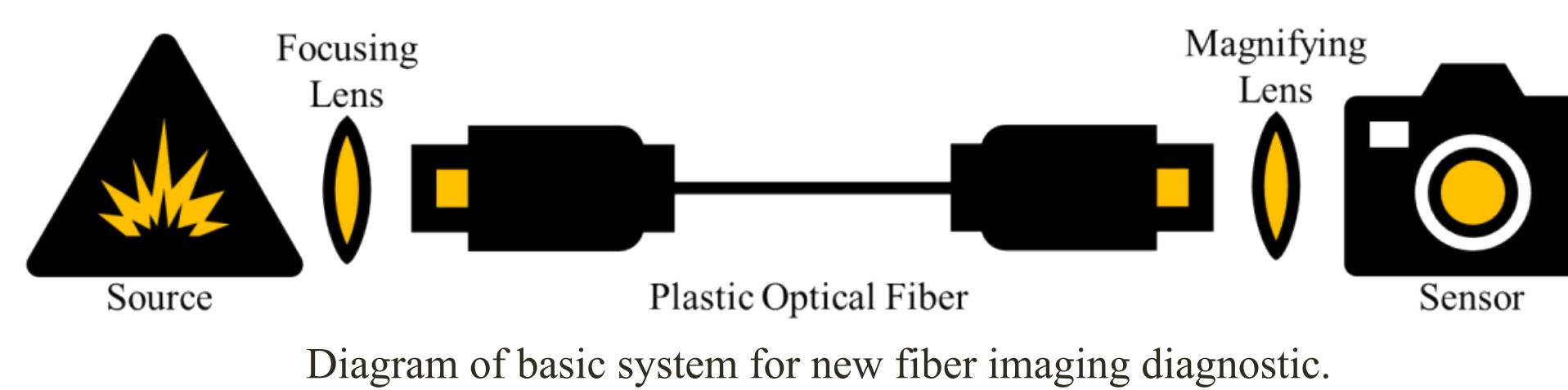
(a) Sandia National Laboratories, (b) University of New Mexico



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- ❖ Fast and easy installation
- ❖ Image multiple positions simultaneously

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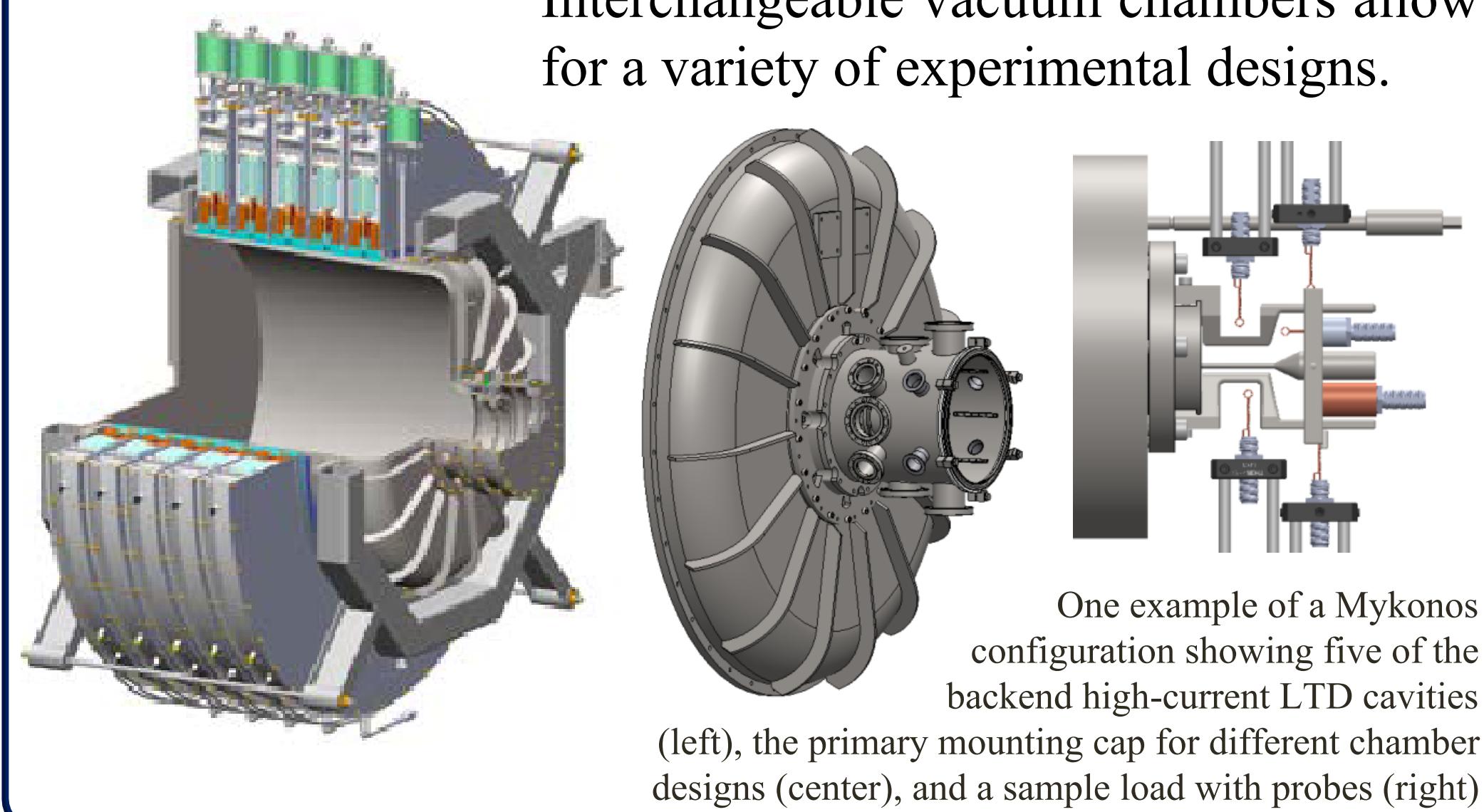
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Interchangeable vacuum chambers allow for a variety of experimental designs.



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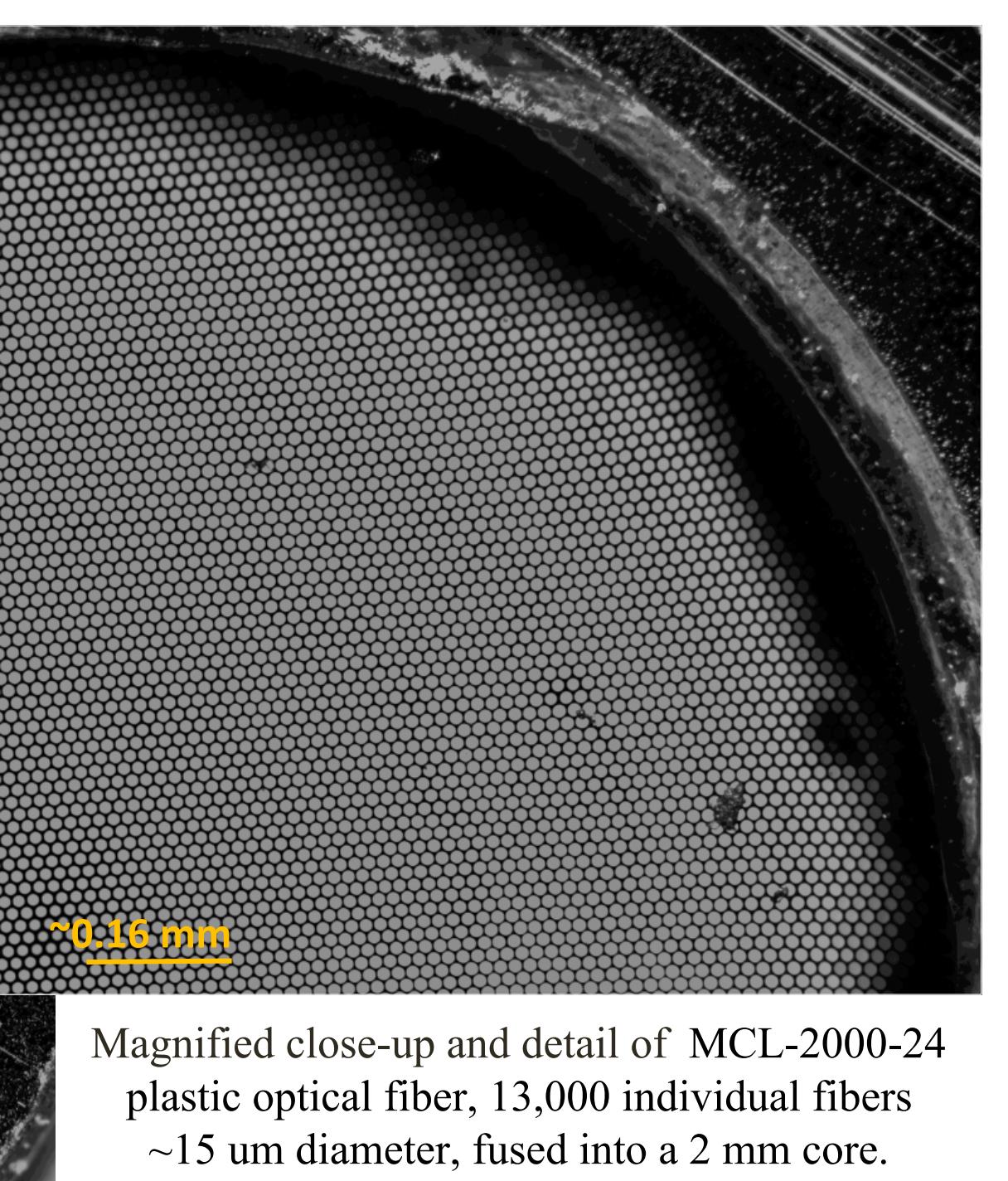
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Plastic Optical Fiber

- ❖ MCL-2000-24 (Asahi Kasei Corporation)

- Core: polymethyl methacrylate (PMMA)
- Jacket: polyethylene (PE)
- 13,000 individual fibers, each core ~15 micron in diameter
- 2 mm diameter fused core, 2.4 mm diameter with jacket
- Step-index multimode
- Transmission rate
 - 4.97 ns/m
- Attenuation
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 - Higher loss below 450 nm and above 600 nm
- 0.5 NA
- 1.49 refractive index

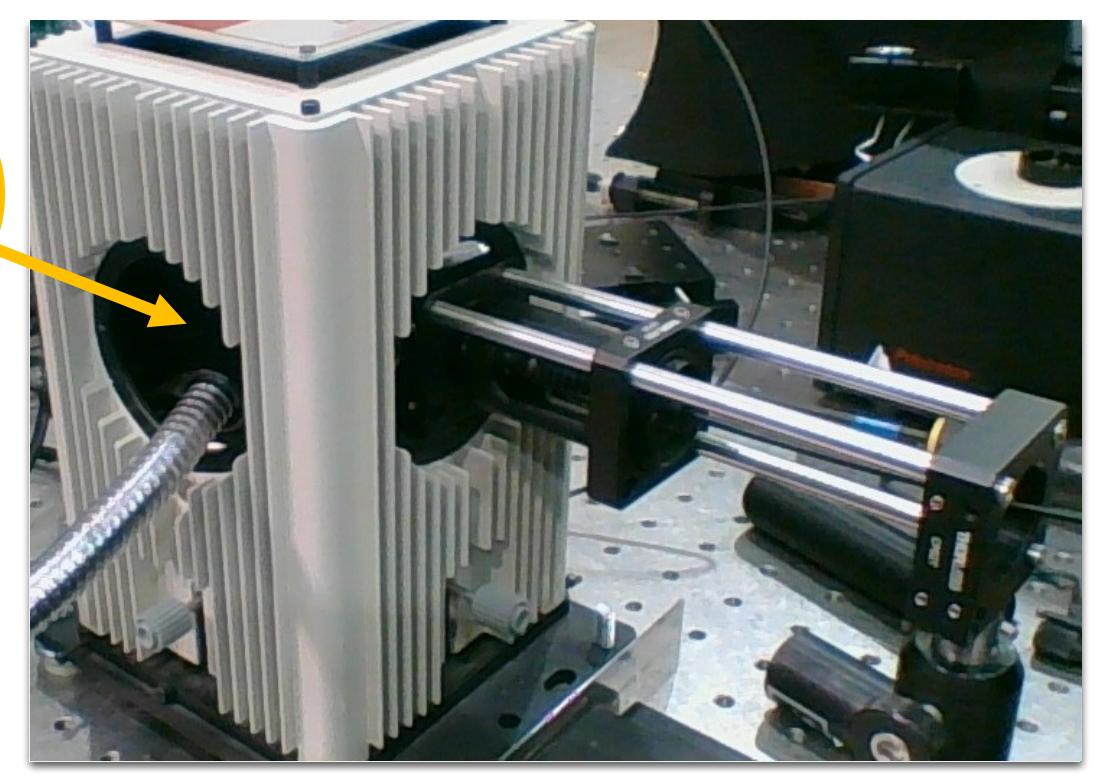


Magnified close-up and detail of MCL-2000-24 plastic optical fiber, 13,000 individual fibers ~15 μm diameter, fused into a 2 mm core.

Source Side

- ❖ Input sources

- Arc lamp, Xenon
 - 9 μs FWHM
 - 800 mJ
- LED with 1951 USAF resolution target

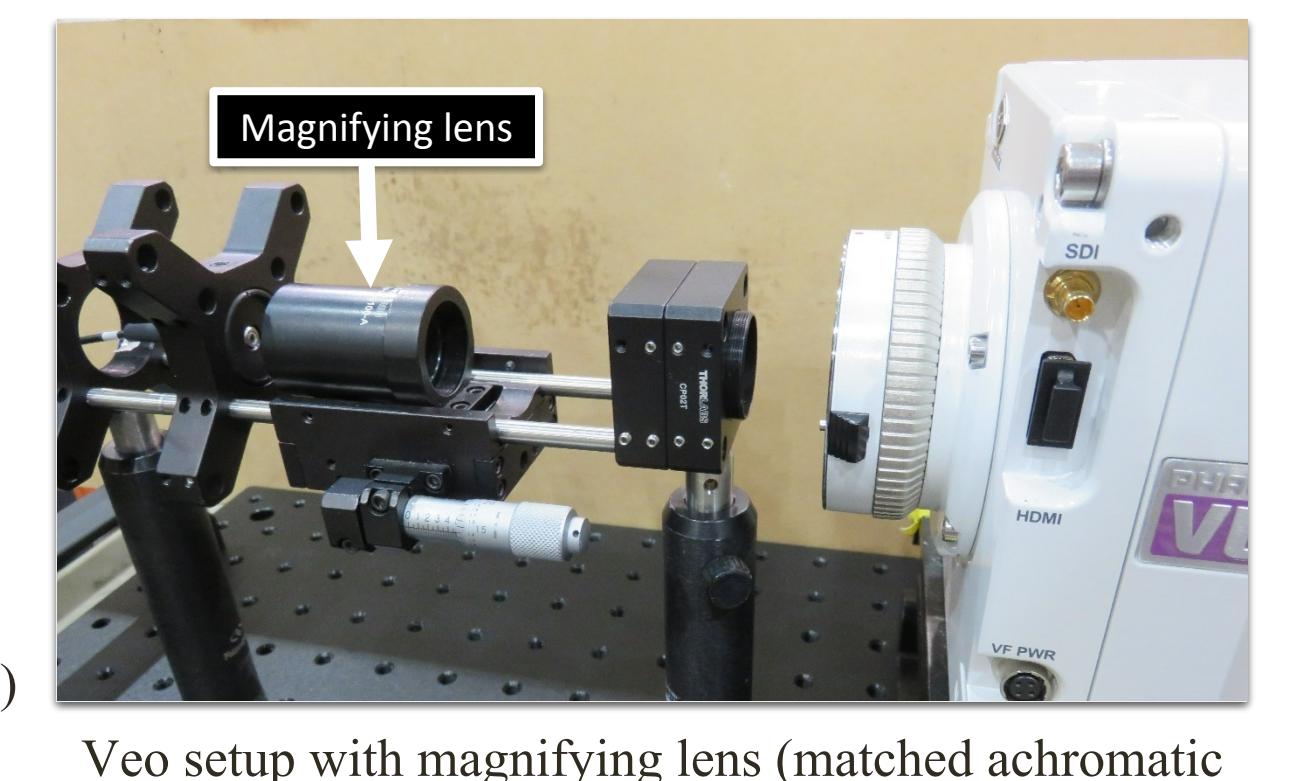


Arc lamp with focusing lens cage system. Detail of interior electrodes.

Sensor Side

- ❖ Focusing lenses

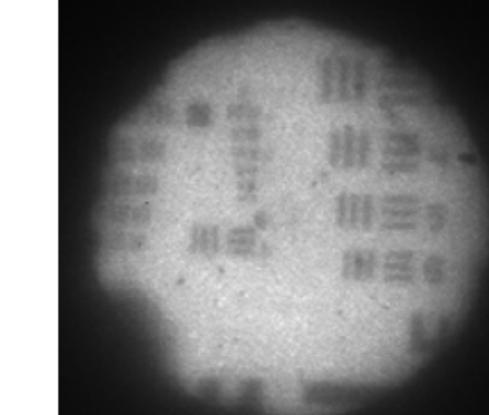
- Small diameter, < 10 mm
- Objective, 20x
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Veo setup with magnifying lens (matched achromatic doublet pair) imaging directly to the sensor.

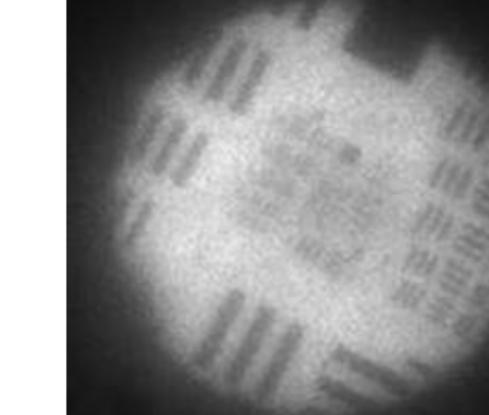
Bench Testing

Small Lens



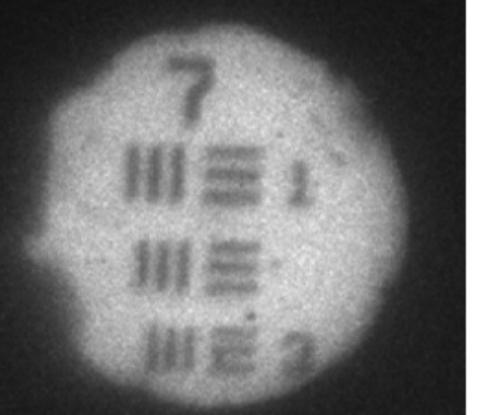
Resolution (6-1 element):
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FOV: 0.3 mm
Target to Lens: 10 mm
Lens to Fiber: 33 mm
Gate: 300 μs

Wide Angle

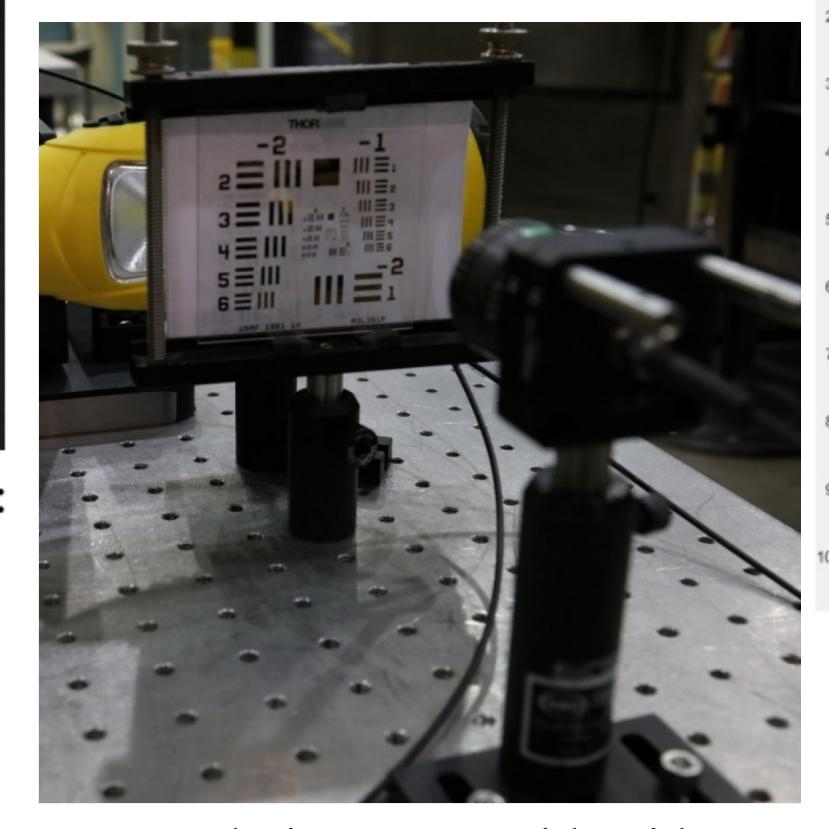


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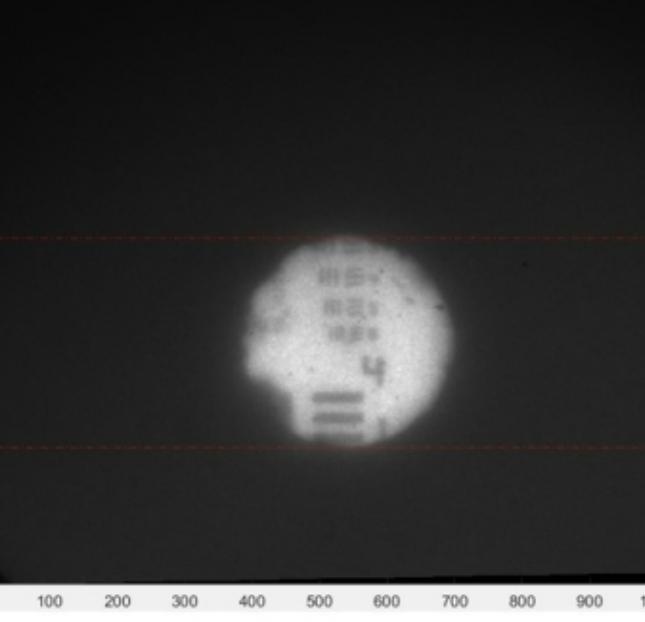
Objective



Resolution (7-2 element):
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Resolution target with wide angle lens and LED



FOV calculation based on USAF resolution target

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(cutting, connectorizing and polishing)

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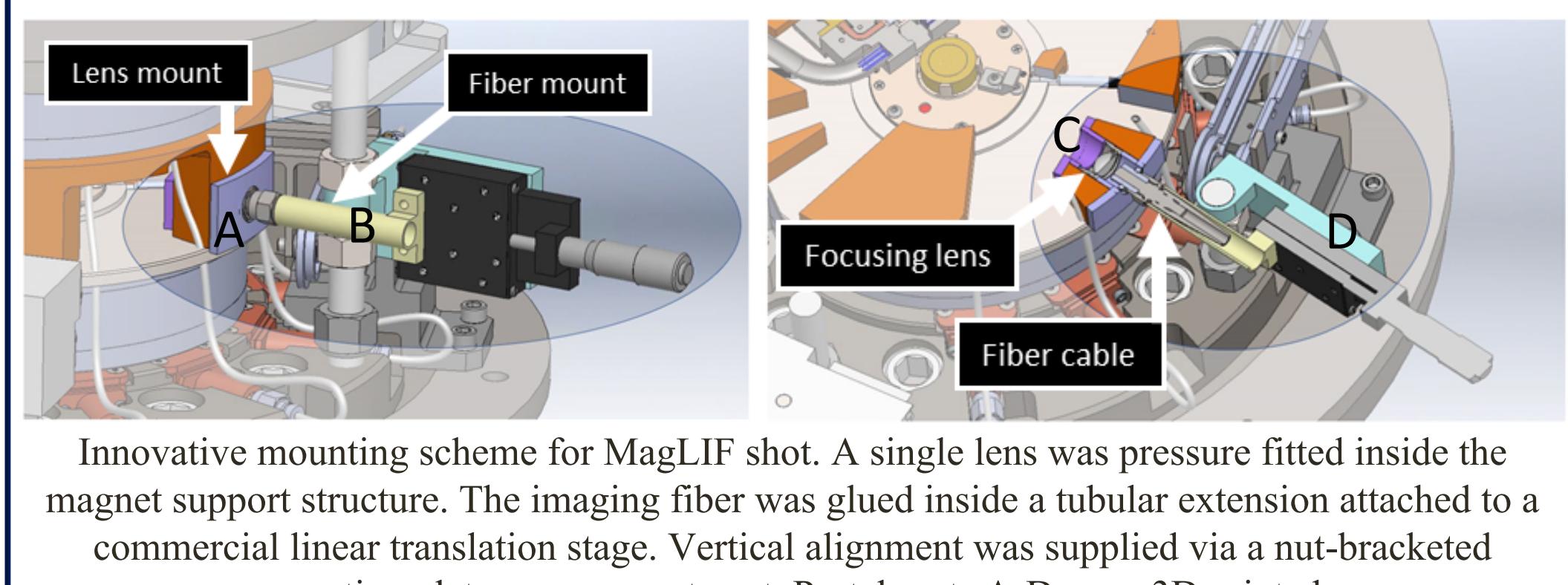
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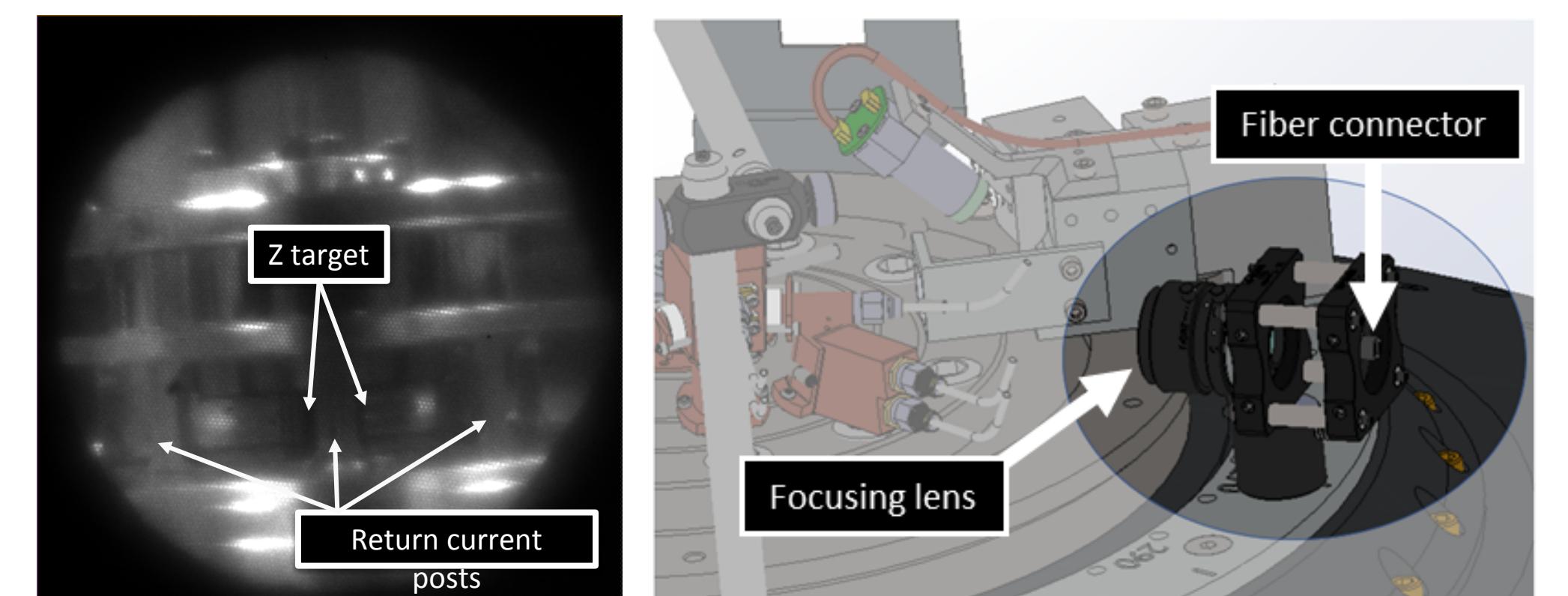
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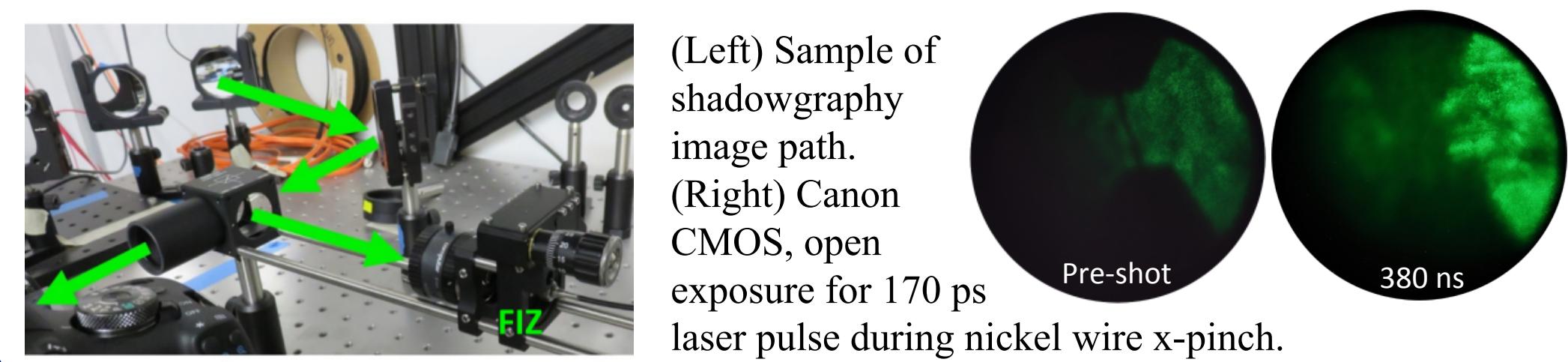
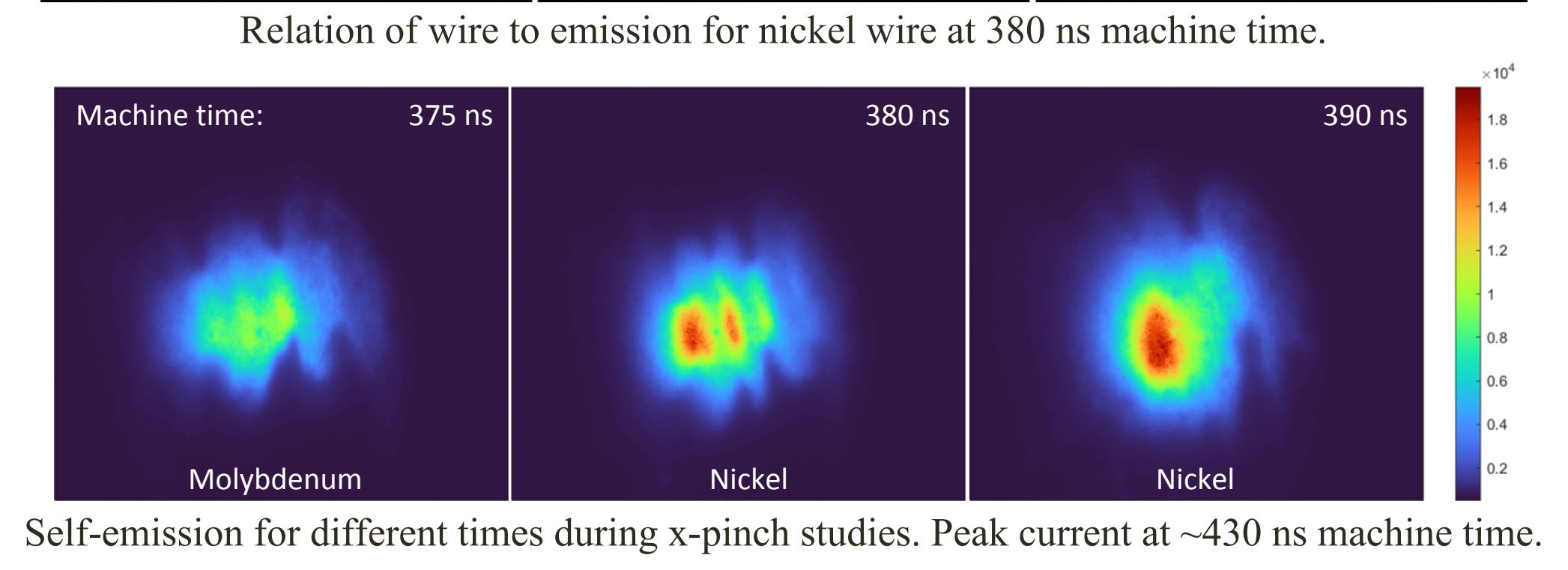
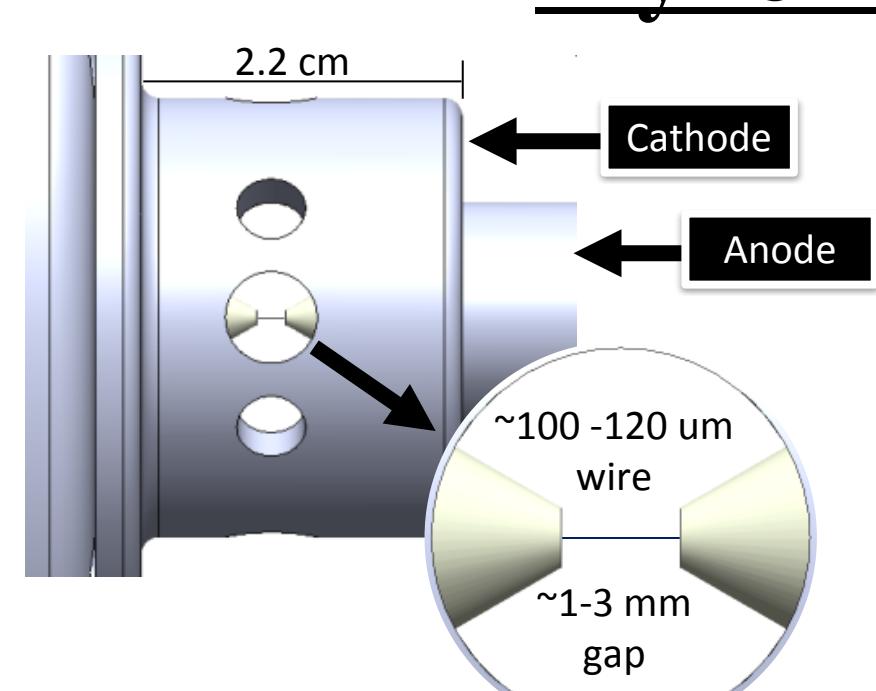


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(Left) Sample of shadowgraphy image path.

(Right) Canon CMOS, open exposure for 170 ps laser pulse during nickel wire x-pinch.



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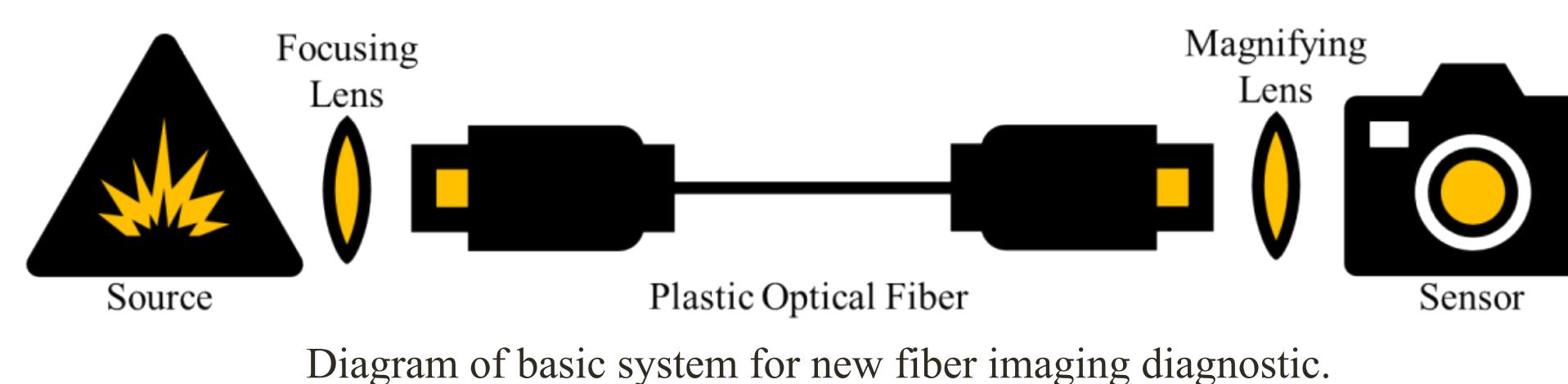
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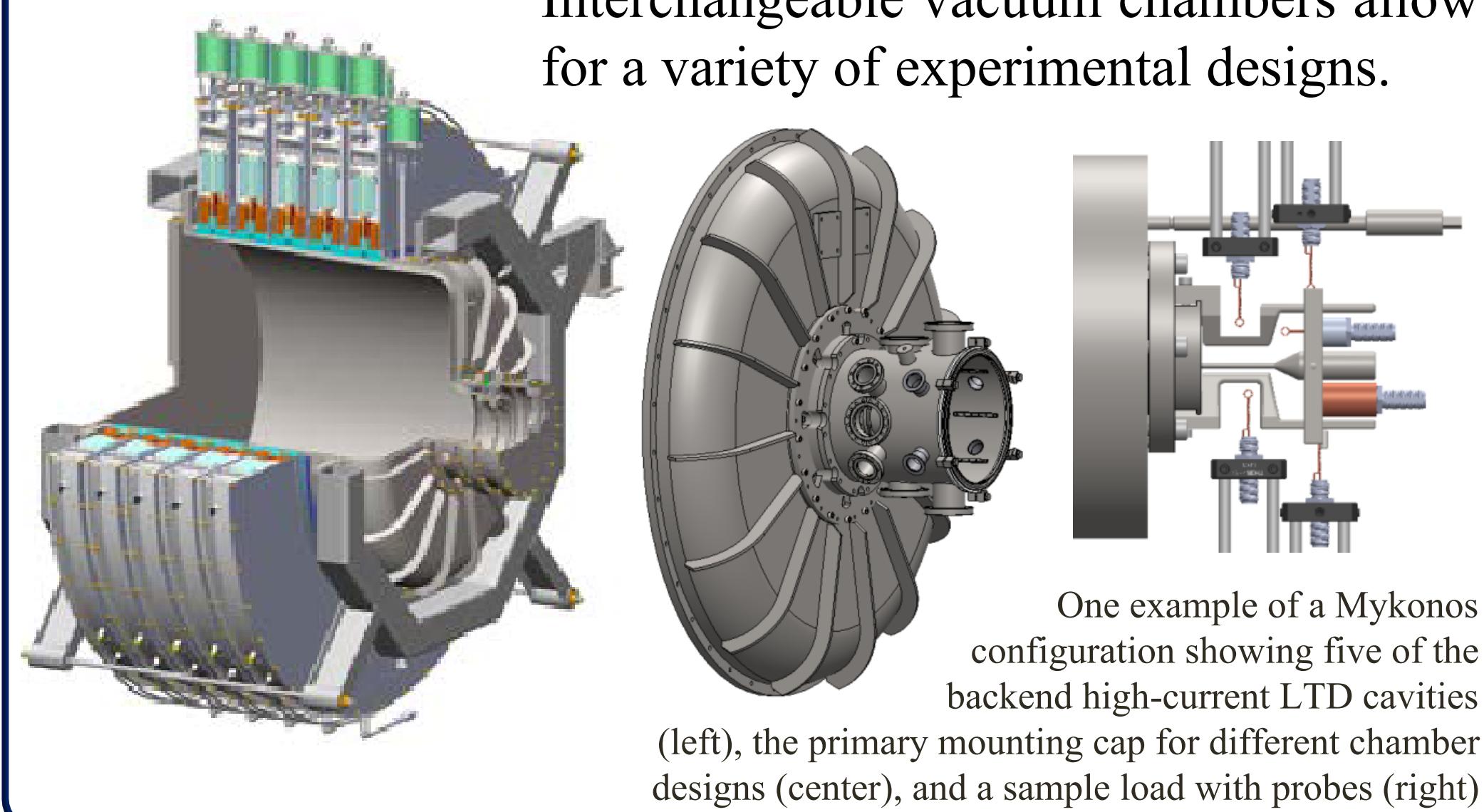
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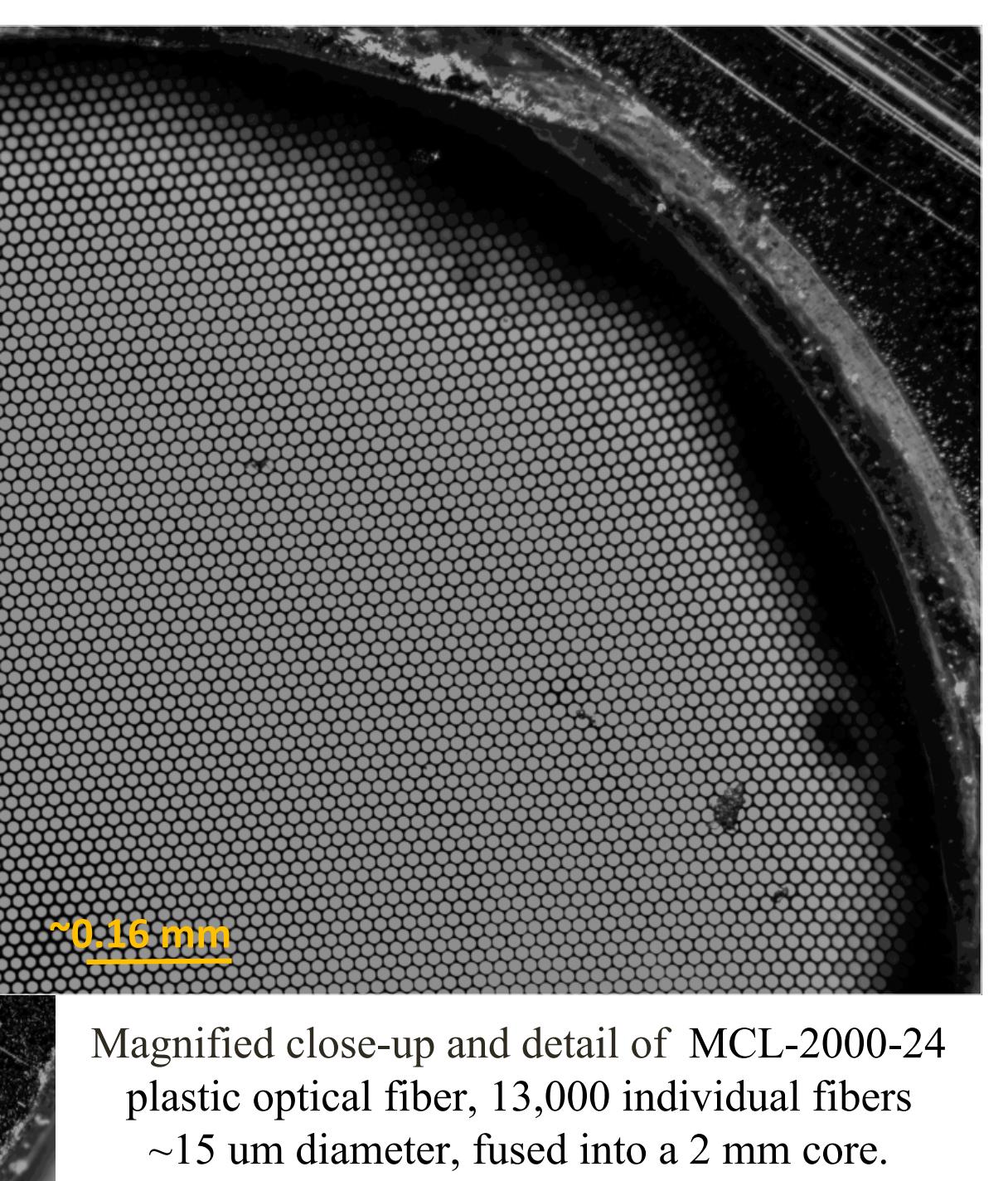
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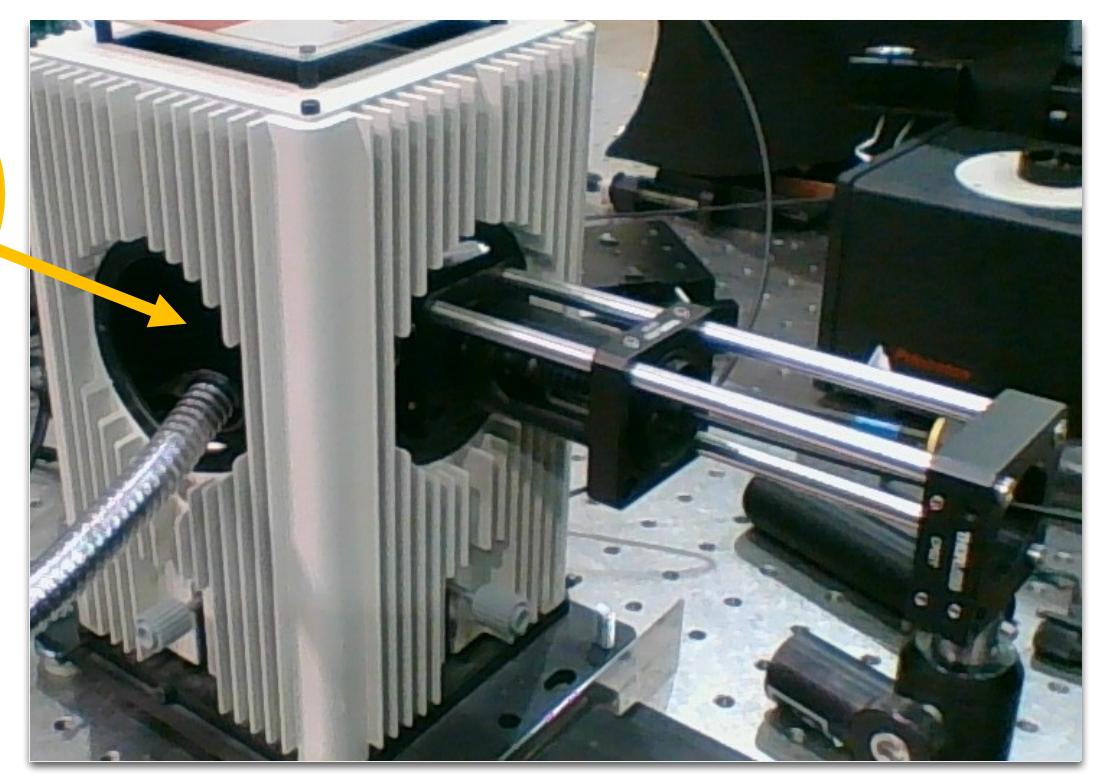


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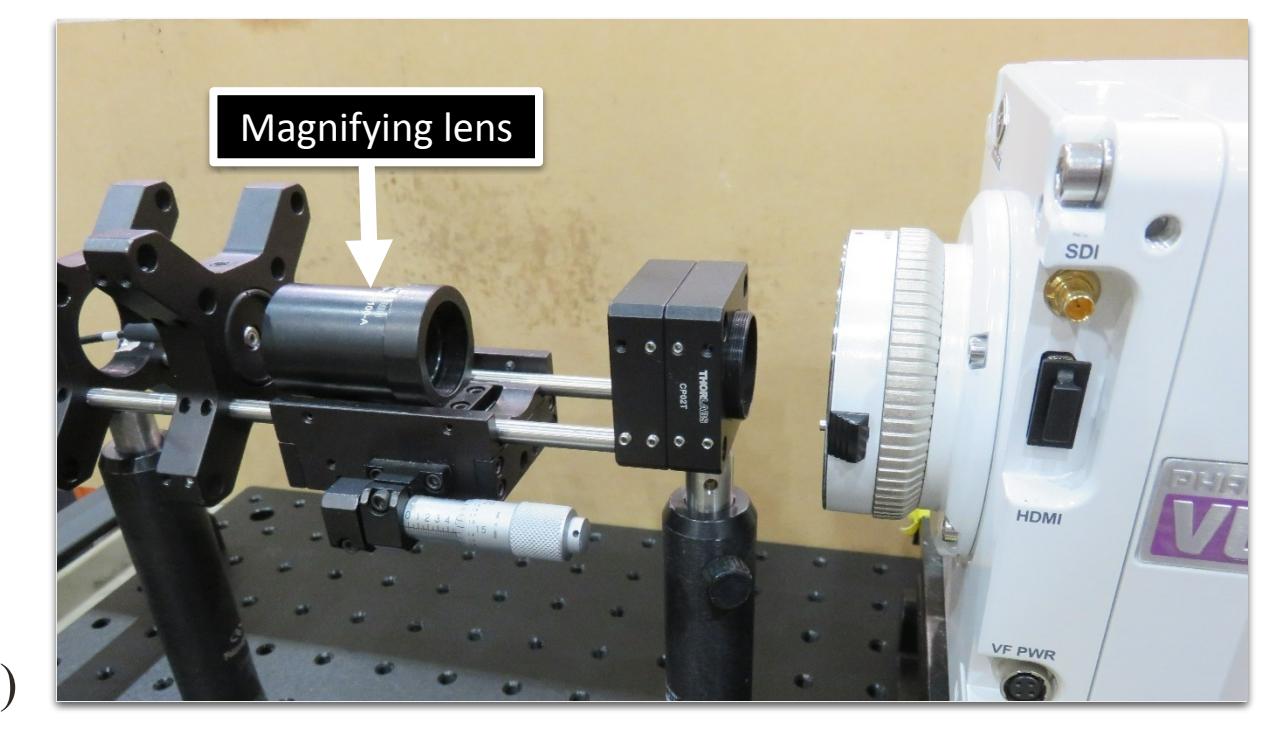


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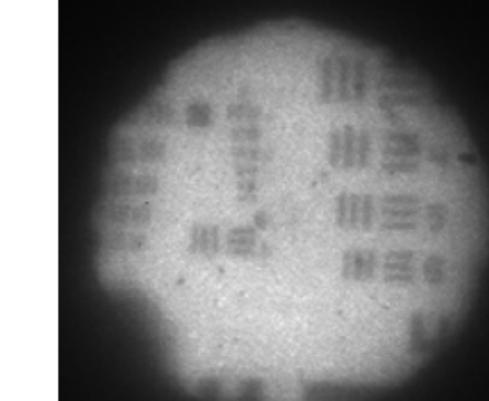
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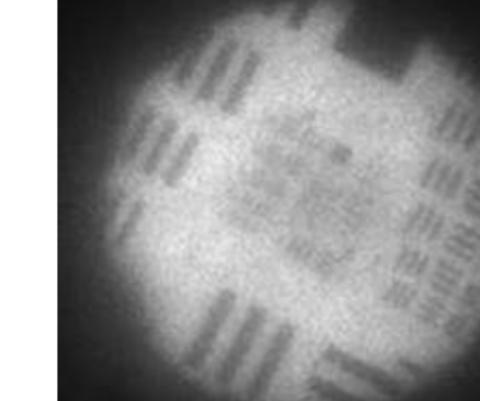
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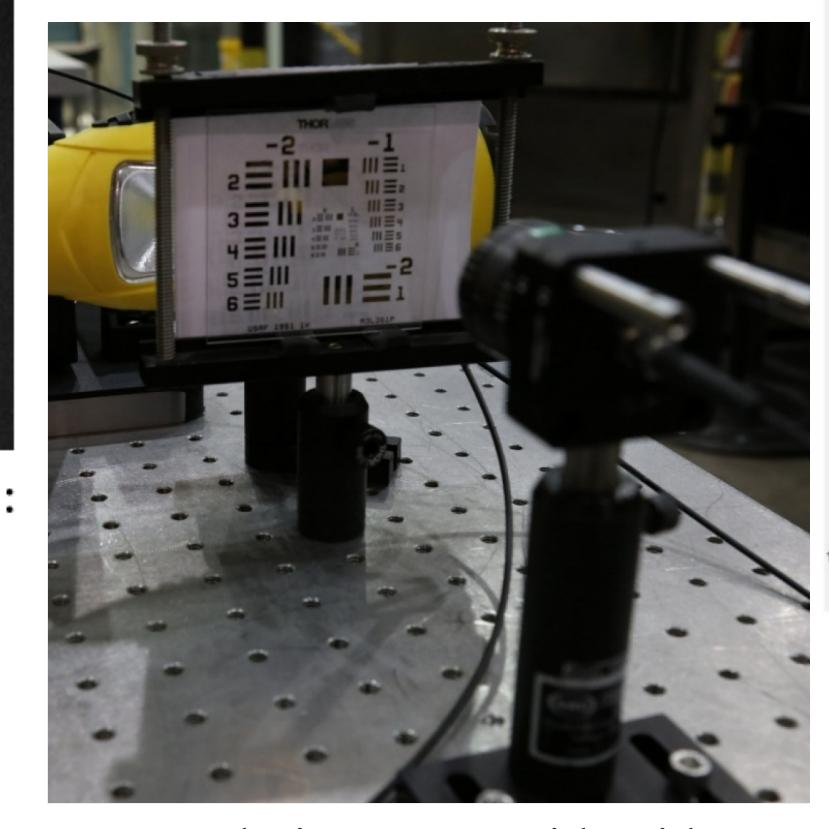


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Resolution target with wide angle lens and LED



FOV calculation based on USAF resolution target

- Resolution (4-1 element) is 31.25 μm (16 lp/mm)
- Average width is 31.5 pixels
- Conversion: 0.99 $\mu\text{m}/\text{pixel}$
- FOV for this image: $0.99 \times 310 = 306.9 \mu\text{m}$

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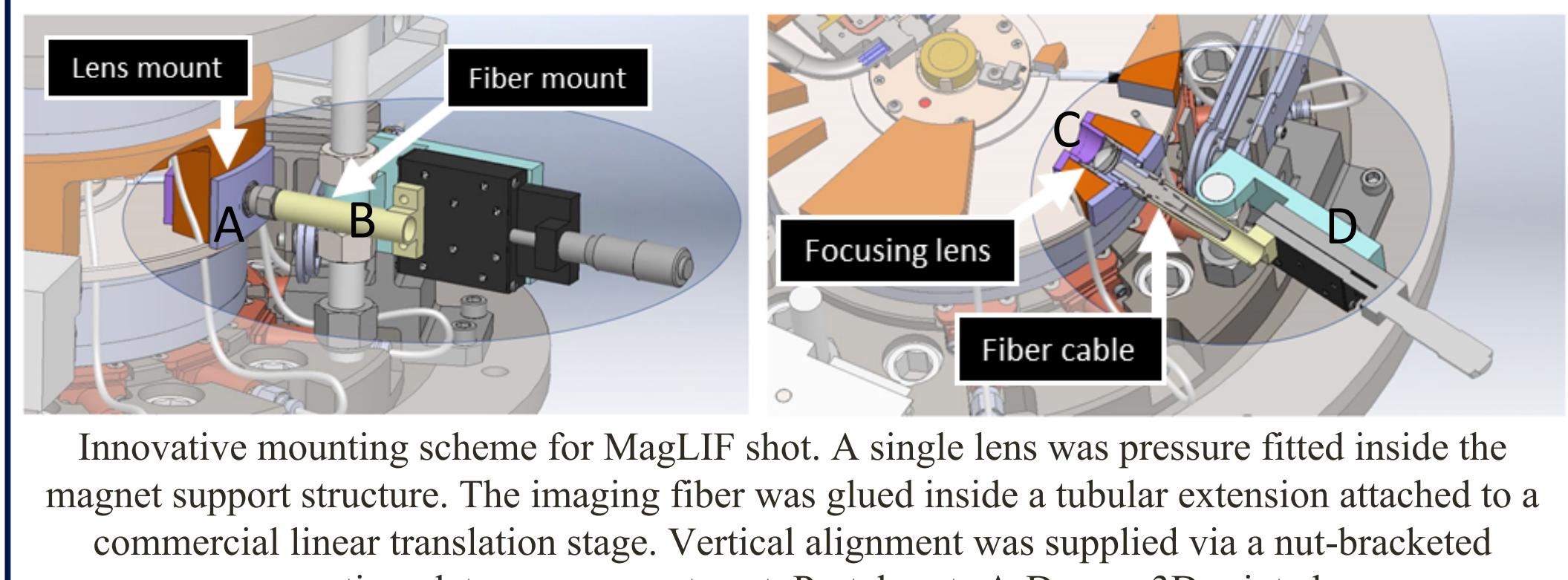
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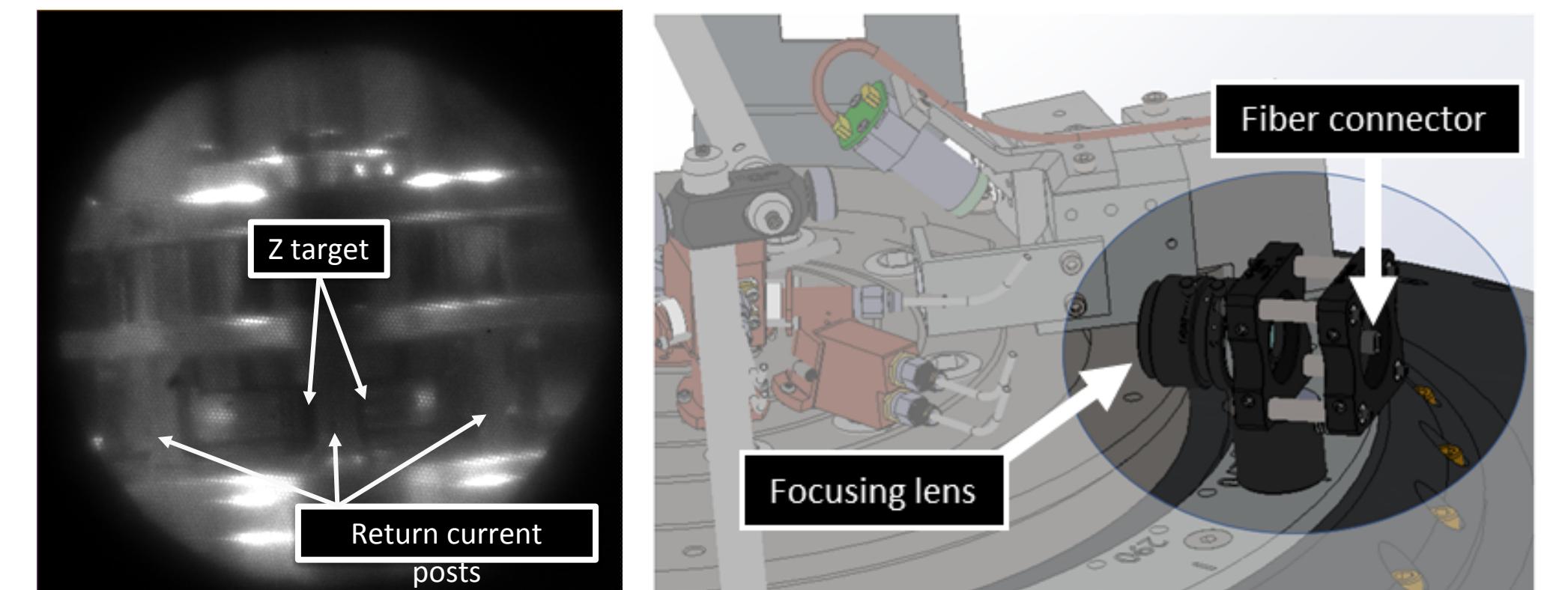
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