International Congress of Cardiology (Stockholm, Sweden, June 19, 2025)

# Minuscule Laser Wakefield Electron Sources for Cardiology

T. Tajima, J. Kuo, and G. Mourou*
University of California at Irvine , CA, 92697 USA
* Ecole Polytechnique, Palaiseau, 91128 France

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Table of contents

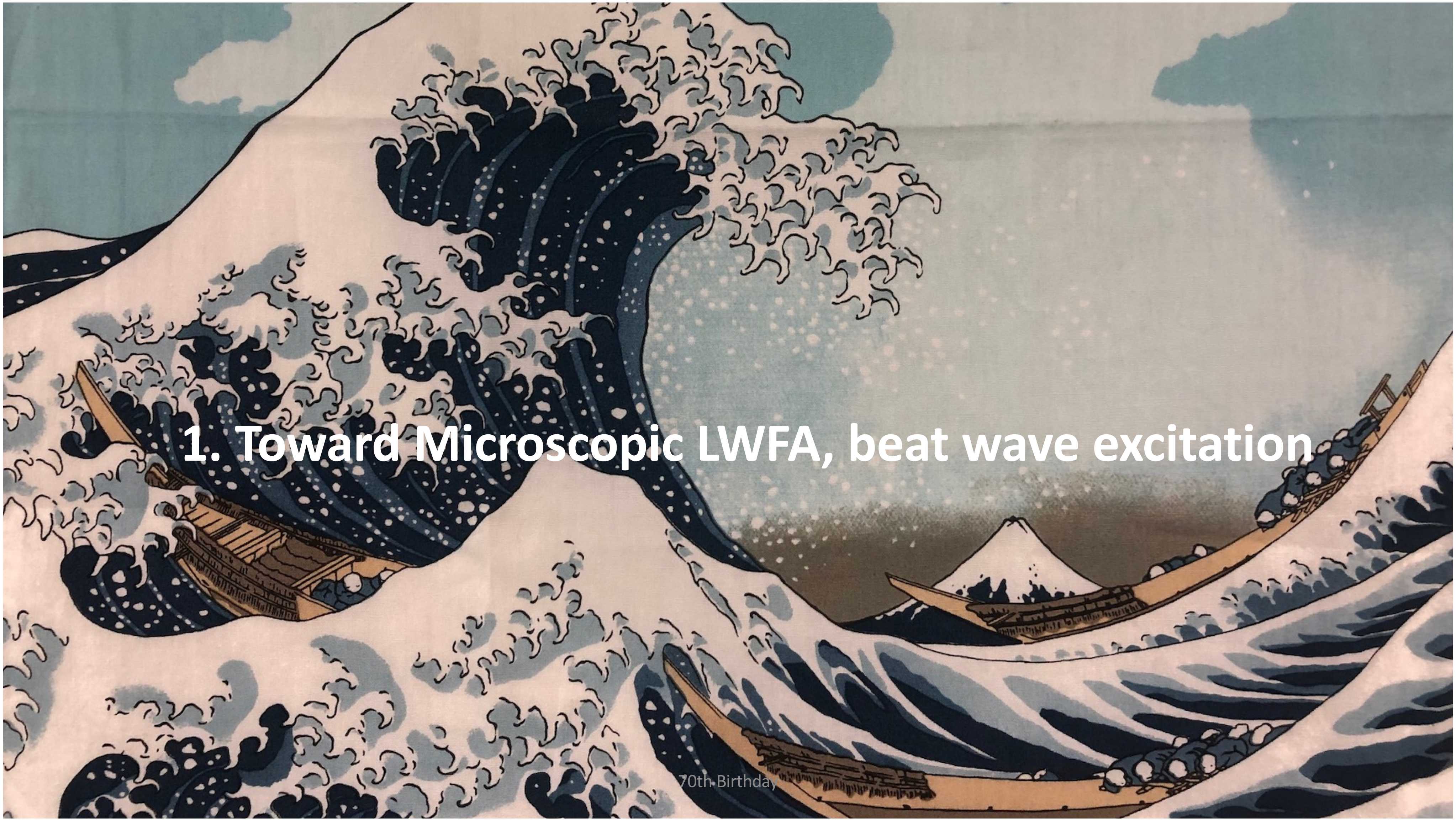
# Minuscule Laser Wakefield Electron Sources for Cardiology

1. Laser wakefield accelerators (LWFA, 1979)

2. Toward Microscopic  LWFA  with fiber laser

3. Toward <u>Endoscopic</u> fiber electrons for cardiology

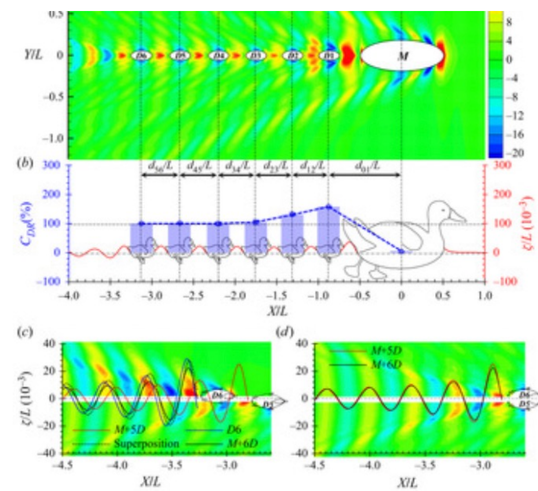
# 1. Toward Microscopic LWFA, beat wave excitation



# Wake

Wake by a duck on a lake:
Nature (or mother duck) shows us

**Wake** by a **laser** pulse
extremely compact (micrometers $\mu$m), extremely intense **acceleration**
(1979, Tajima and Dawson)

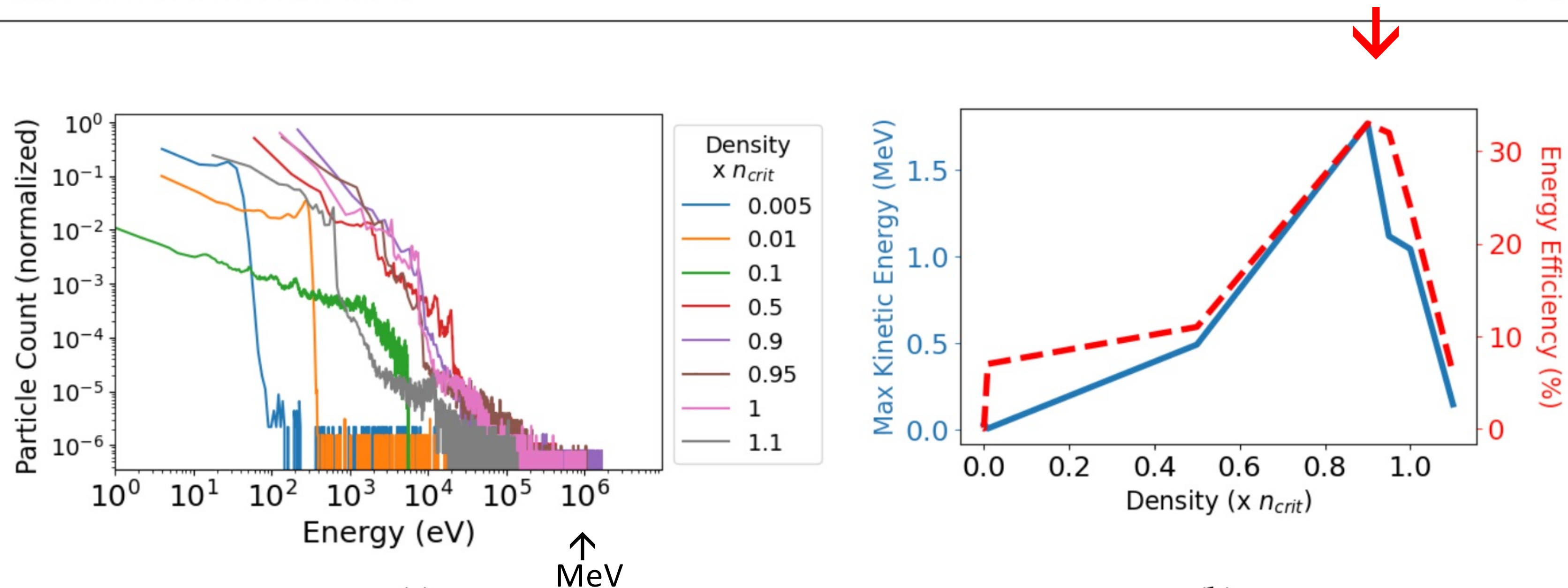


Yuan et al. JFM (2021)

# Simulation study: low intensity laser near critical density

Barraza, Tajima, Strickland, Roa (Photonics, **2022**)

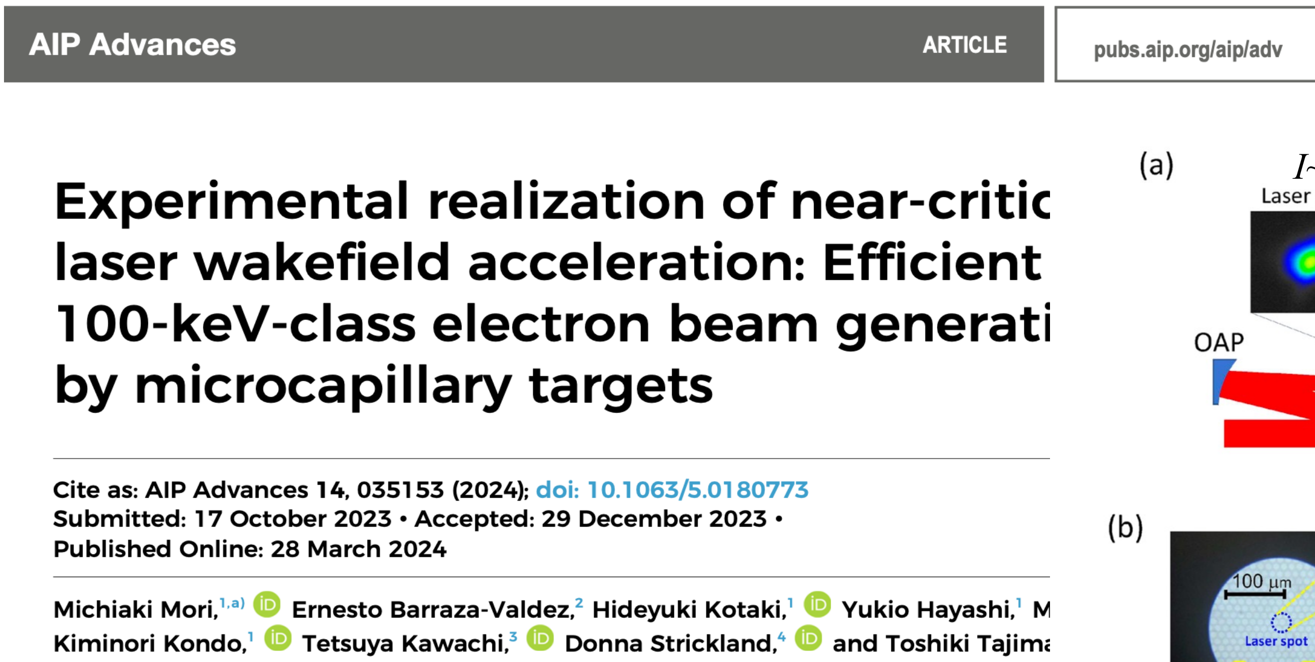
*Photonics* **2022**, *9*, x FOR PEER REVIEW 5 of 11




**(a)** **(b)**

**Figure 3.** Energy distributions, maximum kinetic energies, and laser to total particle energy efficiency with respect to plasma density for BWA simulations after 1 ps using gaussian lasers with intensities of $a_s$, $a_p$ = 0.1, and pulsewidth of 100 fs. The seed laser wavelength was held at $\lambda$ =1 μm

# First Experimental Realization of LWFA in nonrelativistic regime in microcavity (2024)


AIP Advances ARTICLE pubs.aip.org/aip/adv

**Experimental realization of near-critic laser wakefield acceleration: Efficient 100-keV-class electron beam generati by microcapillary targets**

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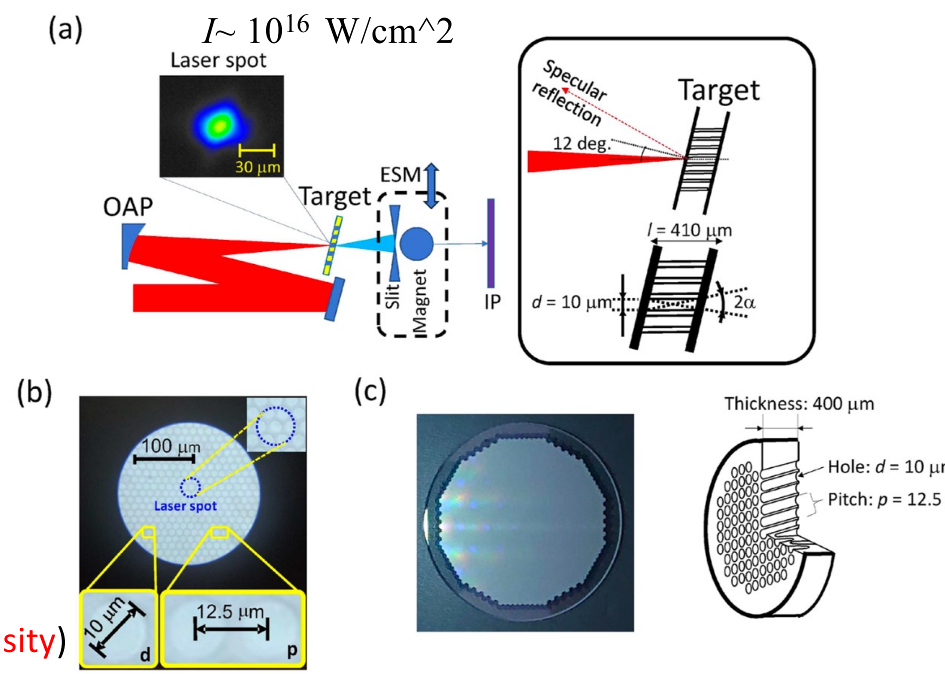
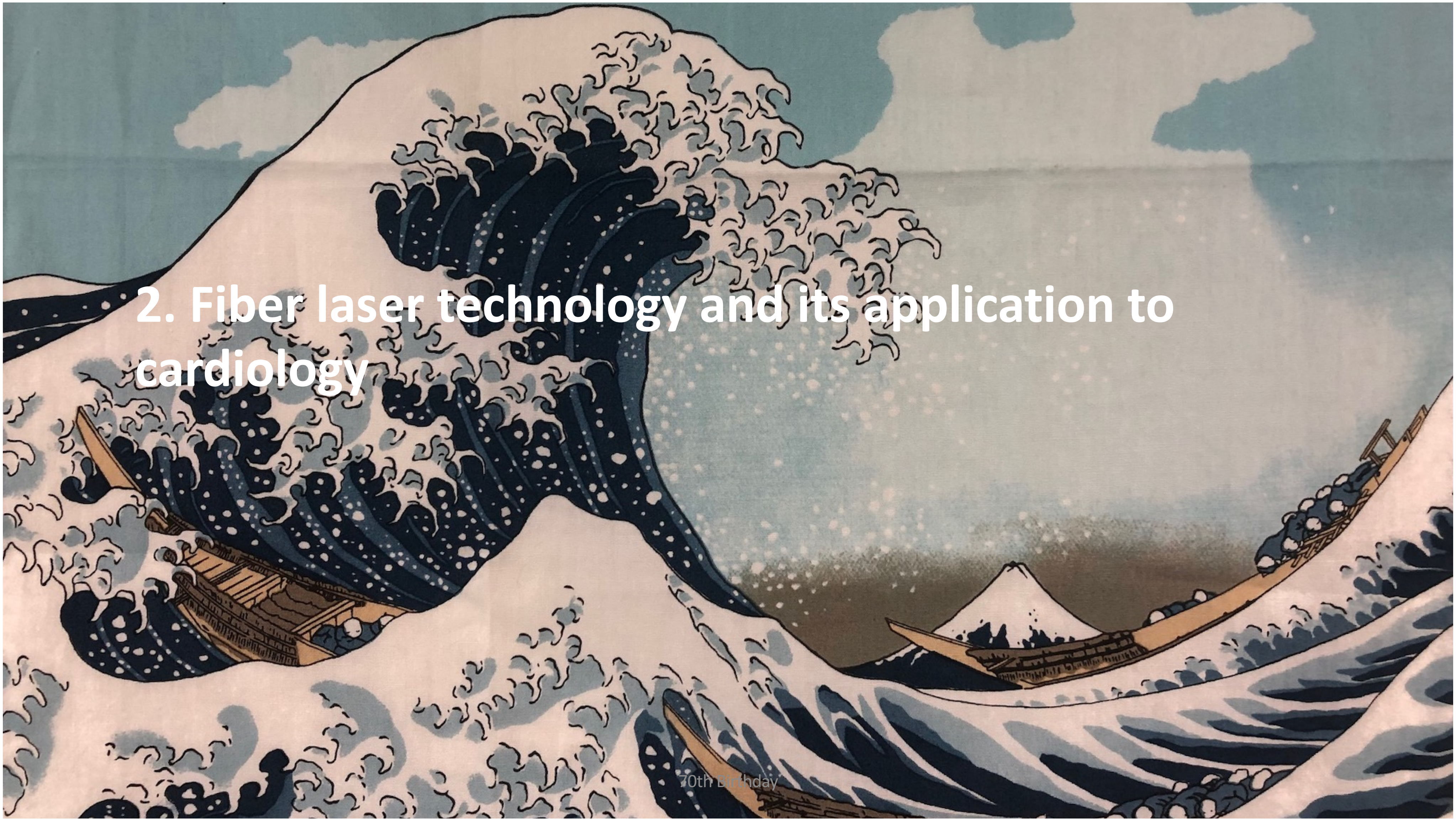
Michiaki Mori,[1,a)] Ernesto Barraza-Valdez,[2] Hideyuki Kotaki,[1] Yukio Hayashi,[1] M
Kiminori Kondo,[1] Tetsuya Kawachi,[3] Donna Strickland,[4] and Toshiki Tajima




(most efficient acceleration by LWFA happens near critical density)

# 2. Fiber laser technology and its application to cardiology



# From Conventional electron accelerator (and X-ray) to Fiber Laser for Therapy

Electron energies by accelerator: 6-20MeV

(→ X-rays)

↓

LWFA provides high dose <u>"FLASH" therapy</u>

↓

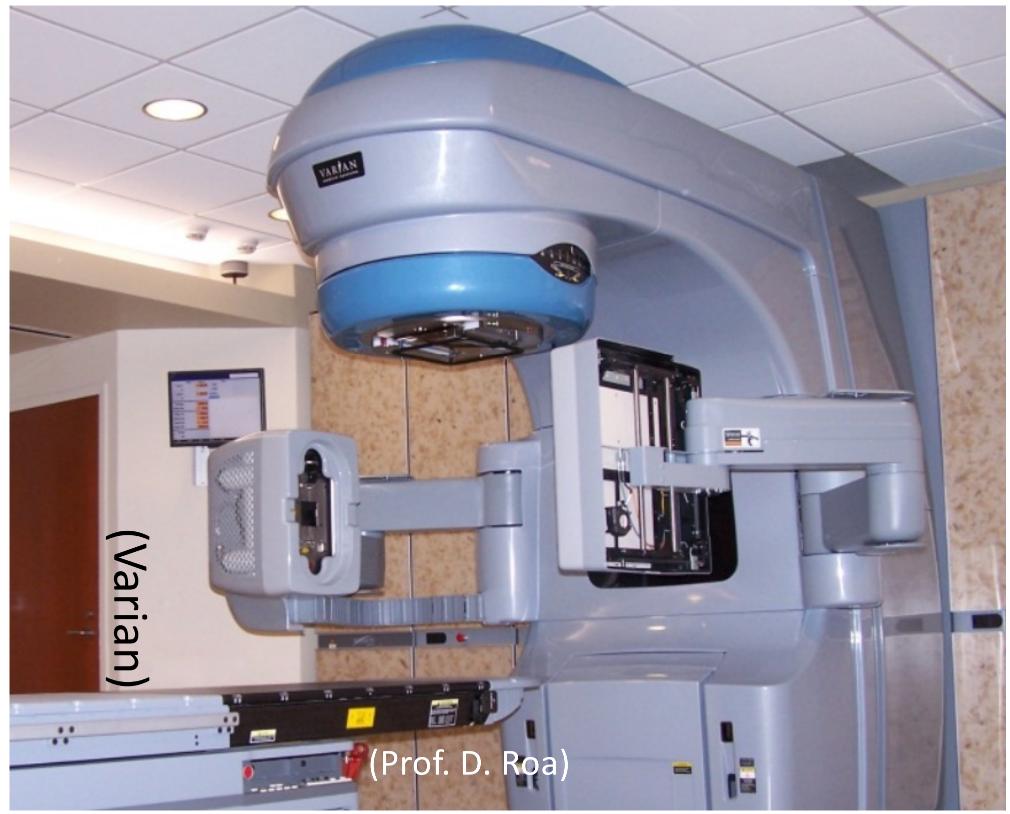
Furthermore, much tinier with **fiber**

$L_e$ ~ 1 cm / 10MeV → 10 micron / 10keV

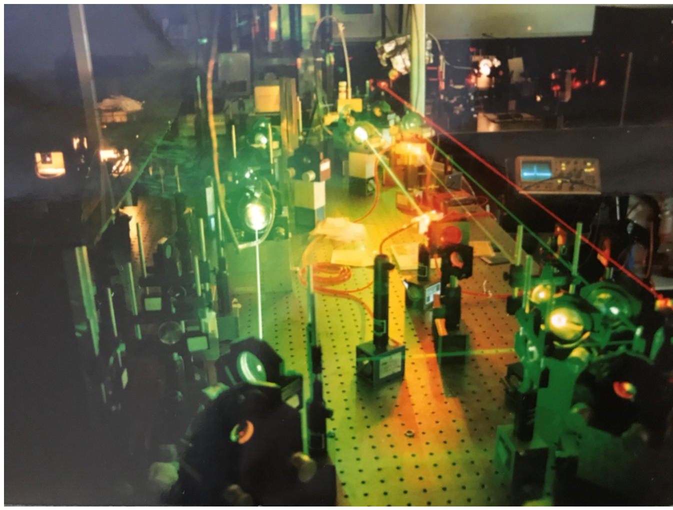
^ Body penetration

↑ Cancer cell size
Capillary size

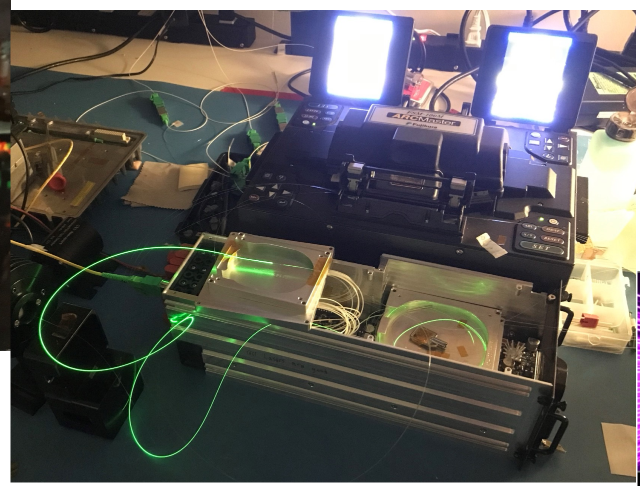
← 5-10m (next room) →



# Free-Space Laser vs. Fiber Laser

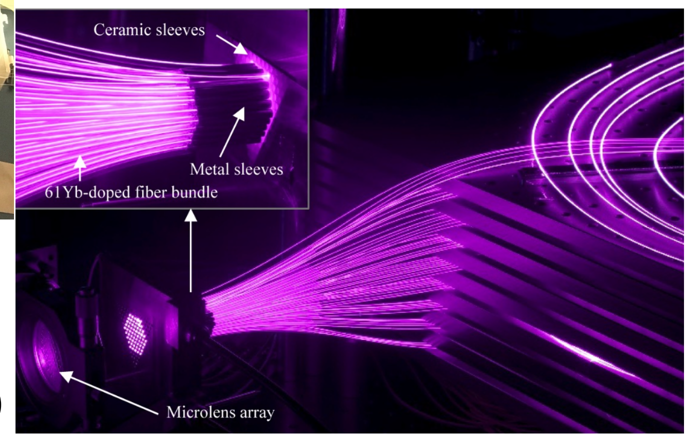


CPA laser
(LWFA stimulated CPA)



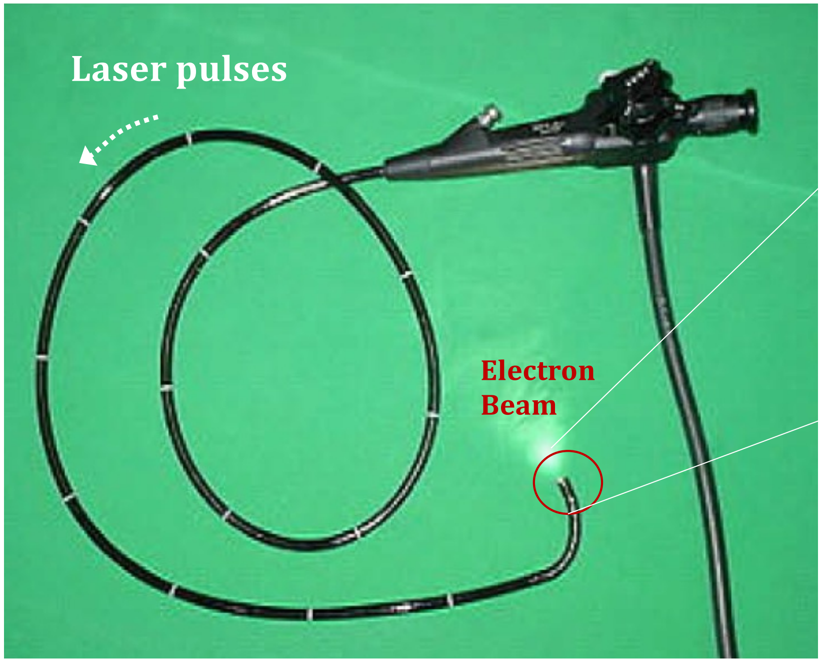
Fiber lasers

(See Dr. W. Sha's talk on Aug. 5, 2024)

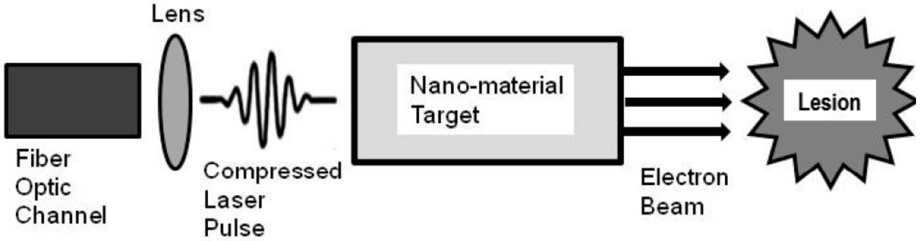



(CAN fiber laser;
Prof. Chanteloup, Aug. 5, 2024)

# Endoscopic Accelerator for Targeted Cancer Therapy




**Micron-scale laser electron accelerator**
**Electron beam 10 – 100 keV**

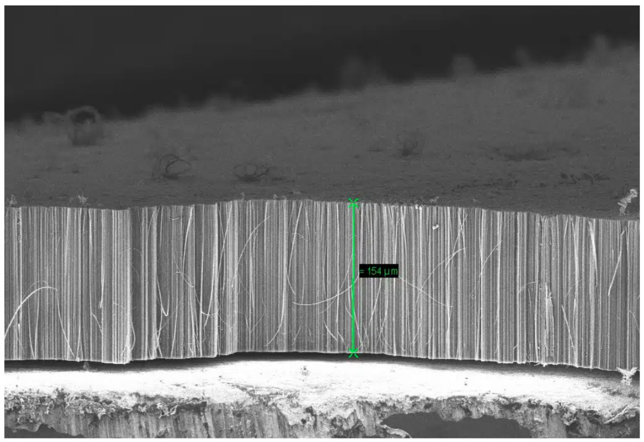


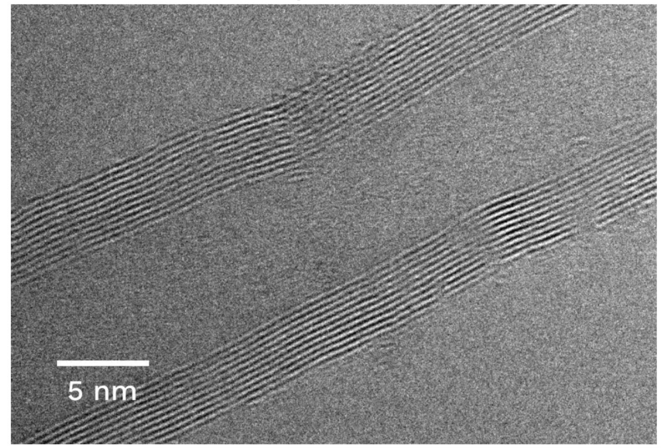

**Near-critical density regime laser plasma acceleration**
$10^{14}$ to $10^{15} W/cm^2$, Gigawatt compact laser

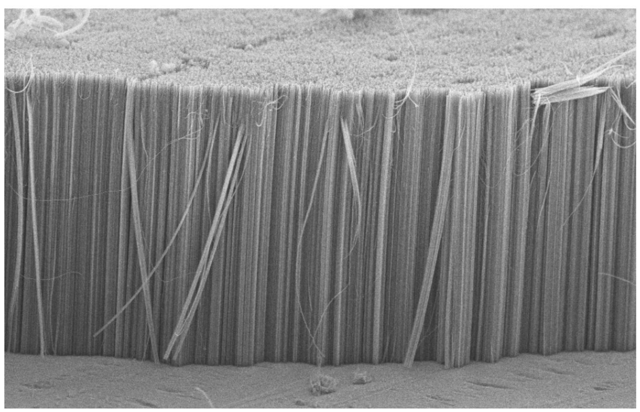
Roa, Kuo, Moyses, Taborek, Tajima, Mourou, and Tamanoi, Photonics (2022)

Carbon nanotubes on a substrate (nm scales):

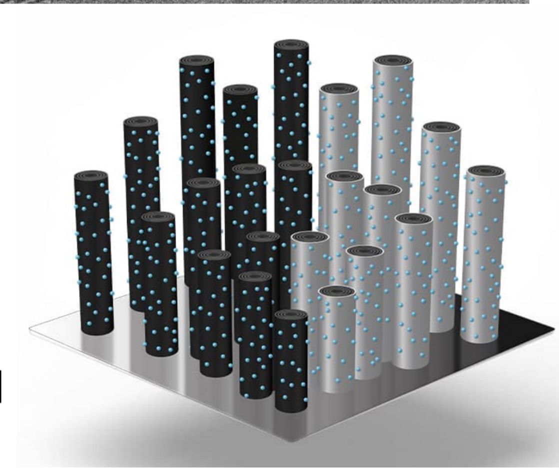
→ toward **Carbon Nanoforest** **(no need for plasma w/vacuum)**



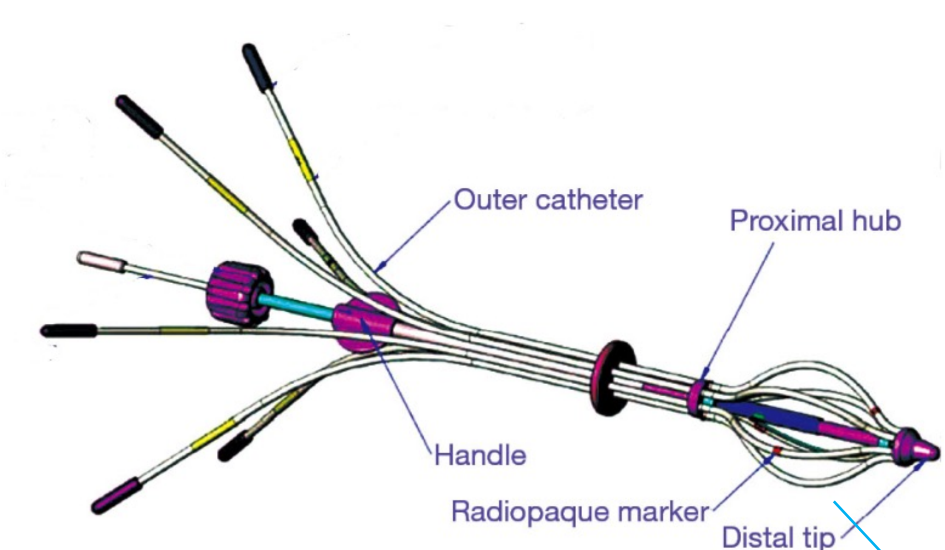


NAWAH



# Hypothetical LWFA cardiac ablation devices



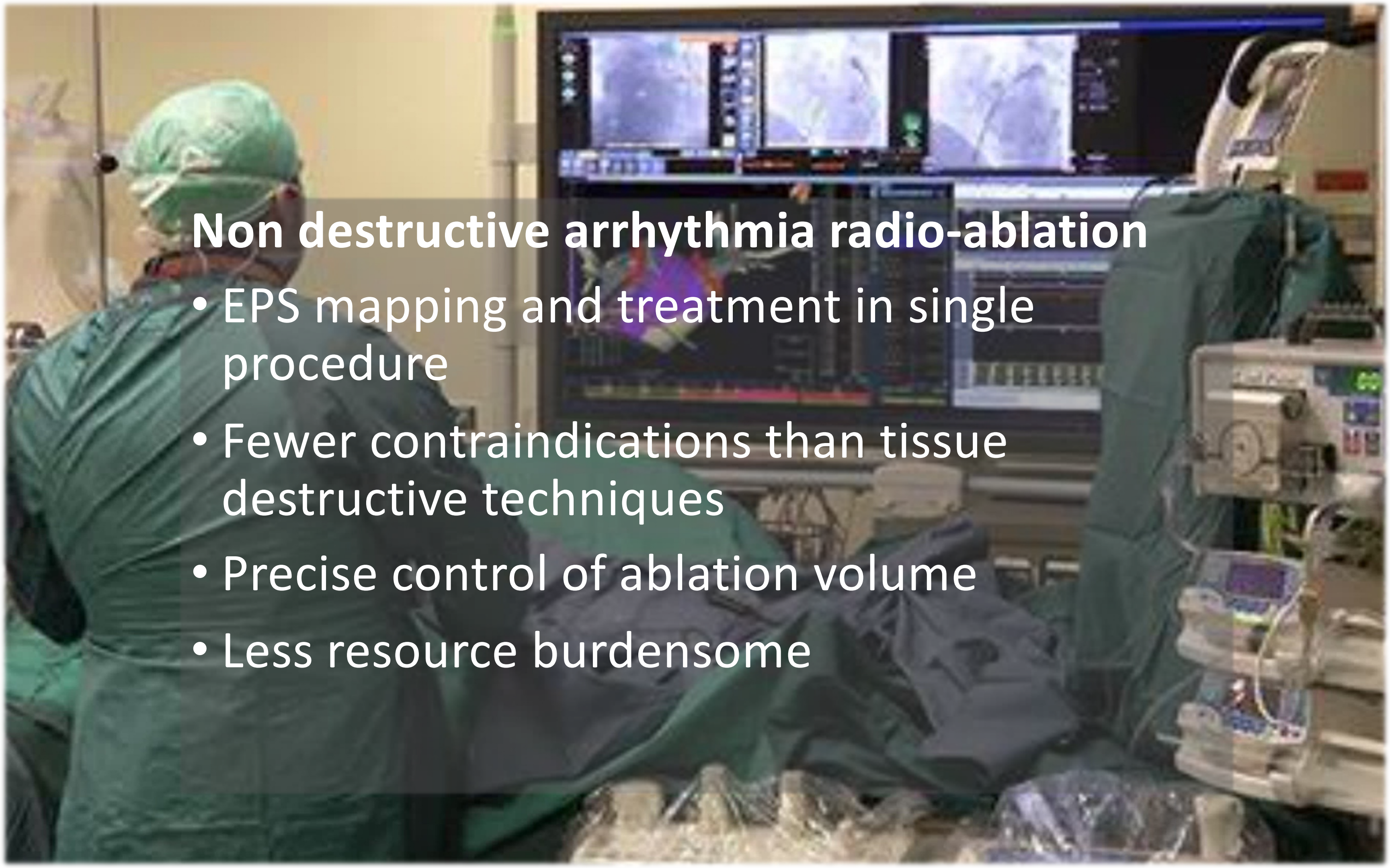

Volumetric radioablation (i.e. a-fib)

Point radioablation (i.e. V-tach)

LWFA channel source(s)
EPS sensors
Ion chambers

# What Can You Do With a Novel Radiation Source?

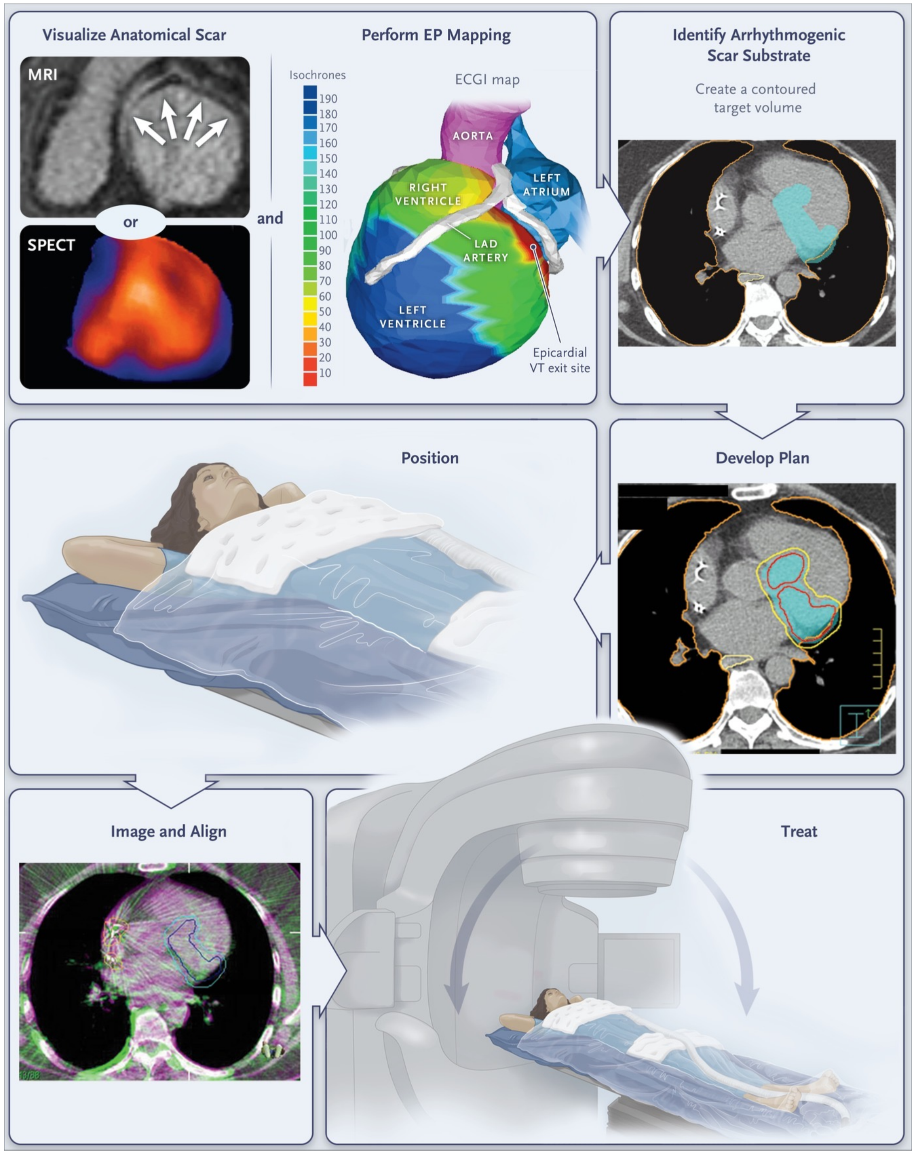
| | **Replace existing radiation technology** | **Replace other technology** | **New applications** |
|---|---|---|---|
| Indications | Same | Same or new | New |
| Toxicities | Less | Same or less | TBD |
| Cost | Same or less | Same or less | TBD |
| Example(s) | ▪ Radionuclide brachytherapy<br>▪ IOERT<br>▪ Superficial electron therapy | ▪ Cardiac arrythmia ablation<br>▪ Radiofrequency ablation | ▪ TBD |



**Non destructive arrhythmia radio-ablation**

- EPS mapping and treatment in single procedure
- Fewer contraindications than tissue destructive techniques
- Precise control of ablation volume
- Less resource burdensome

Extra cardiac tissue ablation




→ Cardiac pathway

s.a.
ventricular tachycardia

Curulich, et al.
N.Engl. J. Med.
(2017)

# cf. Cost **estimate** comparison in the case of radiotherapy

↓

| | <u>**LWFA – HDR**</u> | **Iridium-192–HDR** | **Cobalt-60–HDR** |
|---|---|---|---|
| **Purchase Estimate** | $100K - $300K | $700K - $900K | $700K - $900K |
| **Room Shielding** | None | $200K - $500K | $200K - $500K |
| **Source Replacement** | None | ~$10K every 4-6 months | ~130K every 60 months |
| **Downtime due to Source Replacement** | None | 1-2 days | 1-2 days |

(Prof. Dante Roa, preliminary estimate, 2022)

# Summary

1. Laser wakefield: robust structure and strong compact acceleration

2. Using fiber laser (and carbon nanotube targets) →
   small ( ~ mm) electron sources (100keV-MeV)

3. Endoscopic (through fiber) delivery of electrons for cardiology

Recent advancements in generation of intense X-ray laser ultrashort pulses open opportunities for particle acceleration in solid-state plasmas. Wakefield acceleration in crystals or carbon nanotubes shows promise of unmatched ultra-high accelerating gradients and possibility to shape the future of high energy physics colliders. This book summarizes the discussions of the "Workshop on Beam Acceleration in Crystals and Nanostructures" (Fermilab, June 24–25, 2019), presents next steps in theory and modeling and outlines major physics and technology challenges toward proof-of-principle demonstration experiments.

# Thank you very much!

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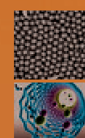
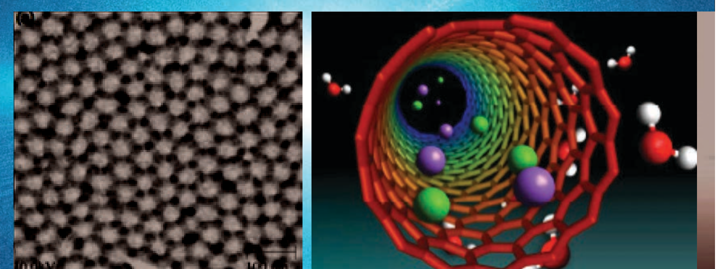
Chattopadhyay • Mourou
Shiltsev • Tajima



BEAM ACCELERATION IN CRYSTALS AND NANOSTRUCTURES

# BEAM ACCELERATION IN CRYSTALS AND NANOSTRUCTURES

Edited by
**Swapan Chattopadhyay • Gérard Mourou**
**Vladimir D. Shiltsev • Toshiki Tajima**



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