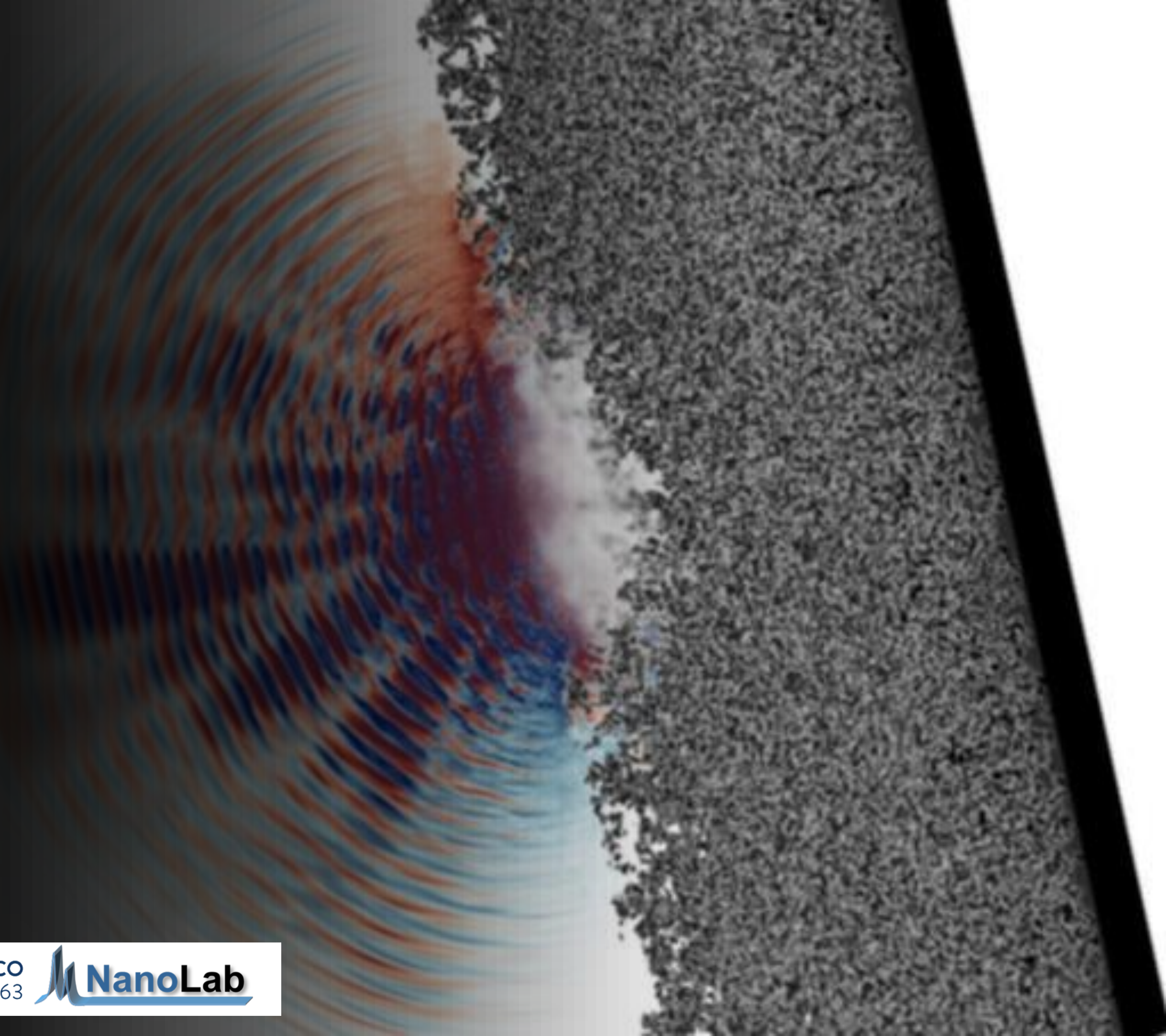
Advanced Target Fabrication @ NanoLab – Politecnico di Milano

Maria Sole Galli De Magistris



Target Fabrication Workshop TARG POLITECNICO MILANO 1863 NanoLab

Laser-Plasma interaction @ NanoLab

Laser driven-processes

- **Ion sources**
- Photon sources
- Neutron sources (p,n)
- p-^{11}B fusion reaction
- **Materials characterization** (e.g. Cultural Heritage)
- Radioisotope production
- Inertial Confinement Fusion

Fundamental physics & applications

Numerical simulations

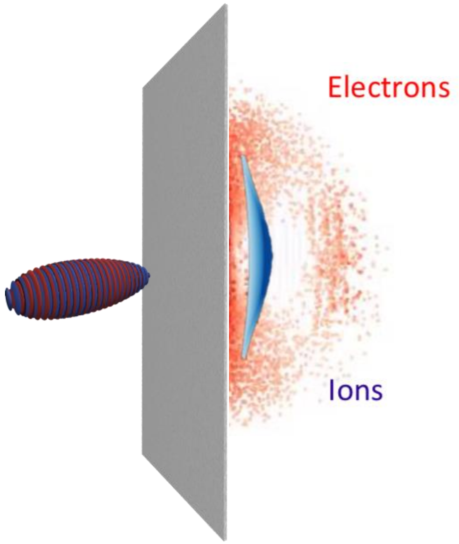
Experimental campaigns

Target fabrication

Solid Targets

Overview on solid targets

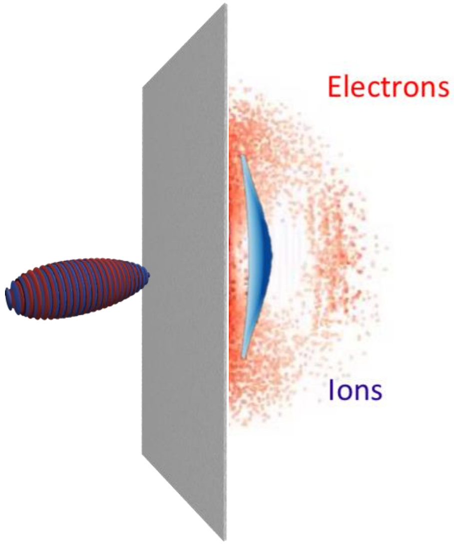
Commercial solid foils



- Widely employed for laser-driven ion acceleration
- **Target properties** depend on **fabrication process**
- **Target properties** not tailored to **laser parameters**
- **Not optimized laser – target coupling**

Overview on solid targets

Commercial solid foils

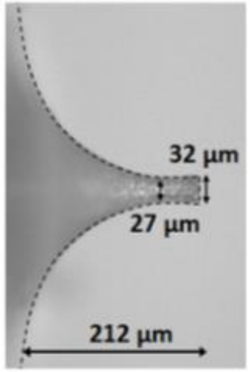


- Widely employed for laser-driven ion acceleration
- **Target properties** depend on **fabrication process**
- **Target properties** not tailored to **laser parameters**
- **Not optimized laser – target coupling**

Advanced solid targets

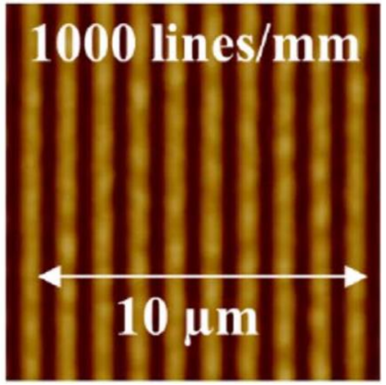
- Tailoring of target properties
- Advanced fabrication techniques

Micro-cone targets



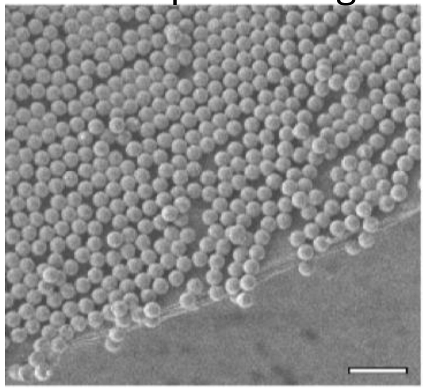
S.A. Gaillard et al J. Phys. 244 (2010) 022034

Grating targets



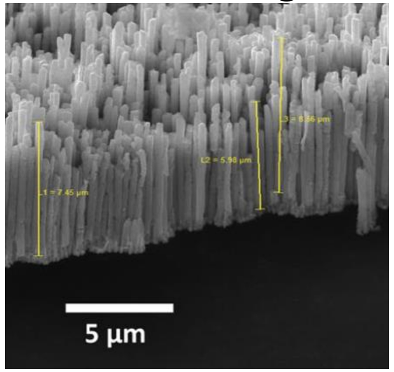
Lad, A.D et al. Sci Rep 12, 16818 (2022)

Microsphere targets



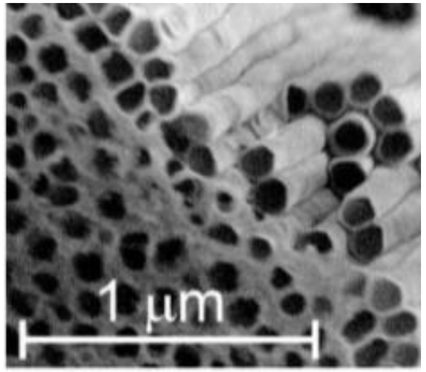
O Klimo et al 2011 New J. Phys. 13 053028

Nanowire targets



Vallières S.et al. Sci Rep (2022)

Nanotube targets

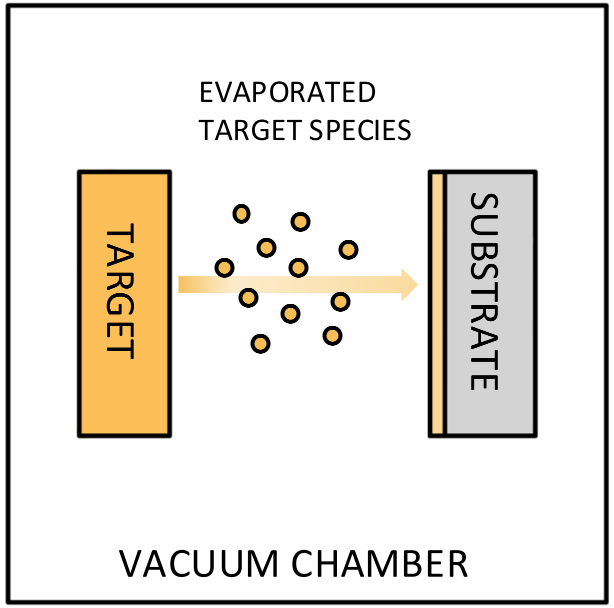


G Cristoforetti et al 2020 Plasma Phys. Control. Fusion 62 114001

Target fabrication @ NanoLab

- **Physical Vapor Deposition** (PVD) techniques
- Many tunable **process parameters**
- Control of **material properties**

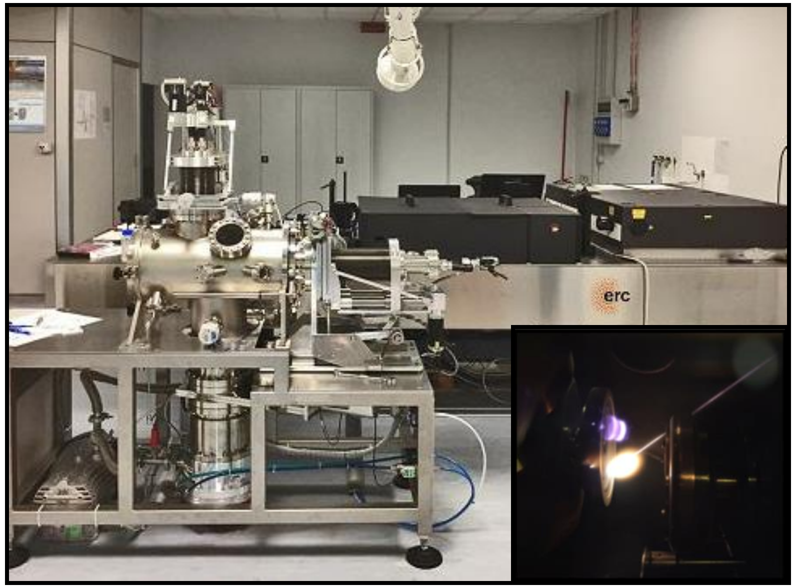
PVD working principle



Magnetron Sputtering (MS)

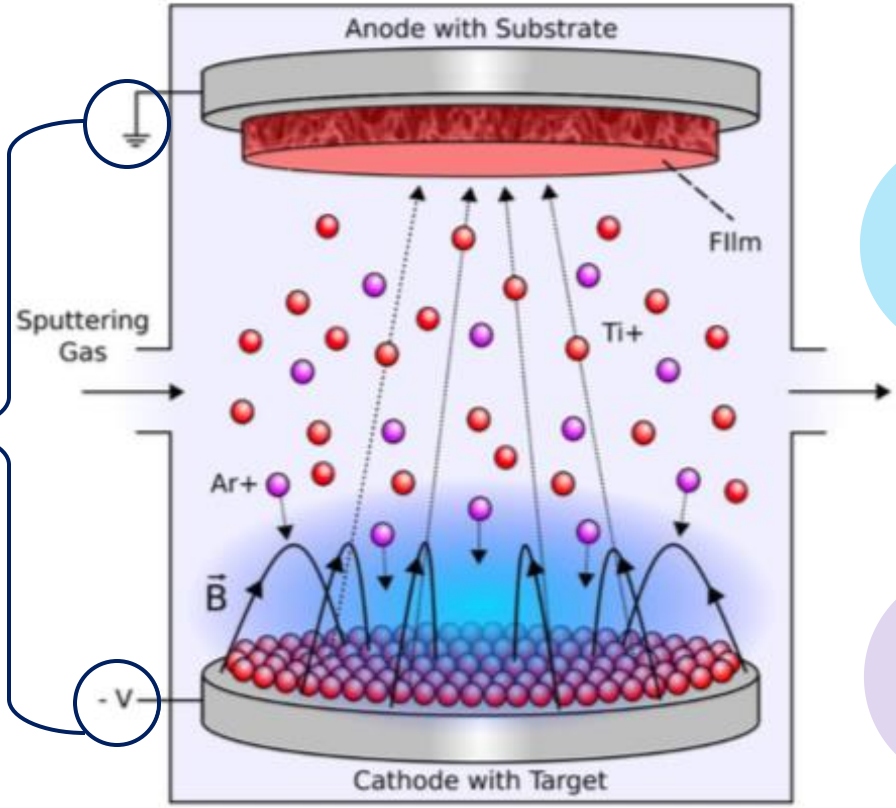
Advanced **nanostructured** solid targets

Pulsed Laser Deposition (PLD)



Target fabrication @ NanoLab : Magnetrons Sputtering (MS)

High (negative) **voltage** between target and substrate



4 Deposition

3 Propagation

2 Plasma confinement

1 Target vaporization by energetic working gas ion

- **High voltage parameters**
- Sputtering power
- Bias voltage
- Magnetic field

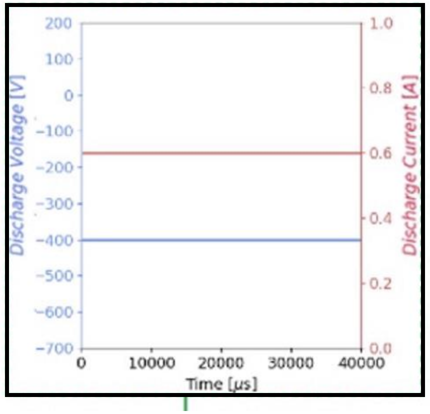
Deposited film properties control

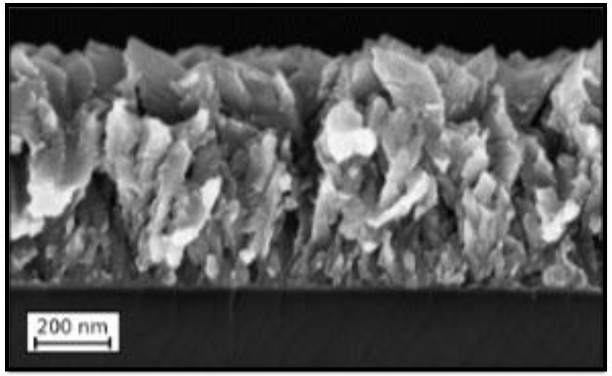
(density, thickness, elemental composition, morphology)

Lundin D. et al., «High Power Impulse Magnetron Sputtering. Fundamentals, Technologies, Challenges and Applications», Elsevier(2020)

Target fabrication @ NanoLab : Magnetron Sputtering (MS)

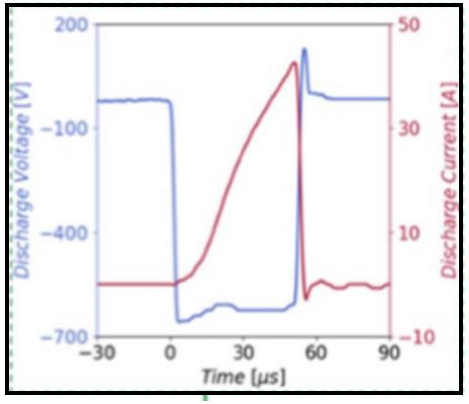
Direct Current Magnetron Sputtering (DCMS)

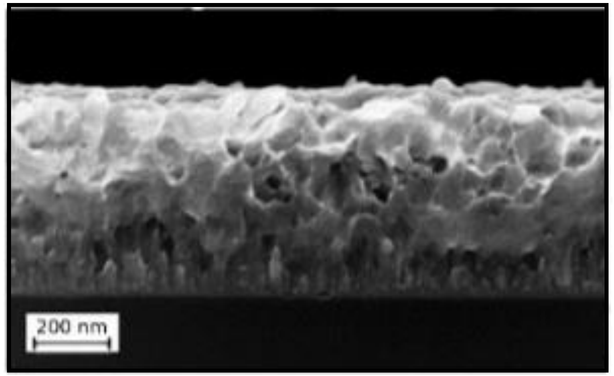




- **Continuous high voltage**
- Mostly neutral species
- Columnar growth
- High deposition rate

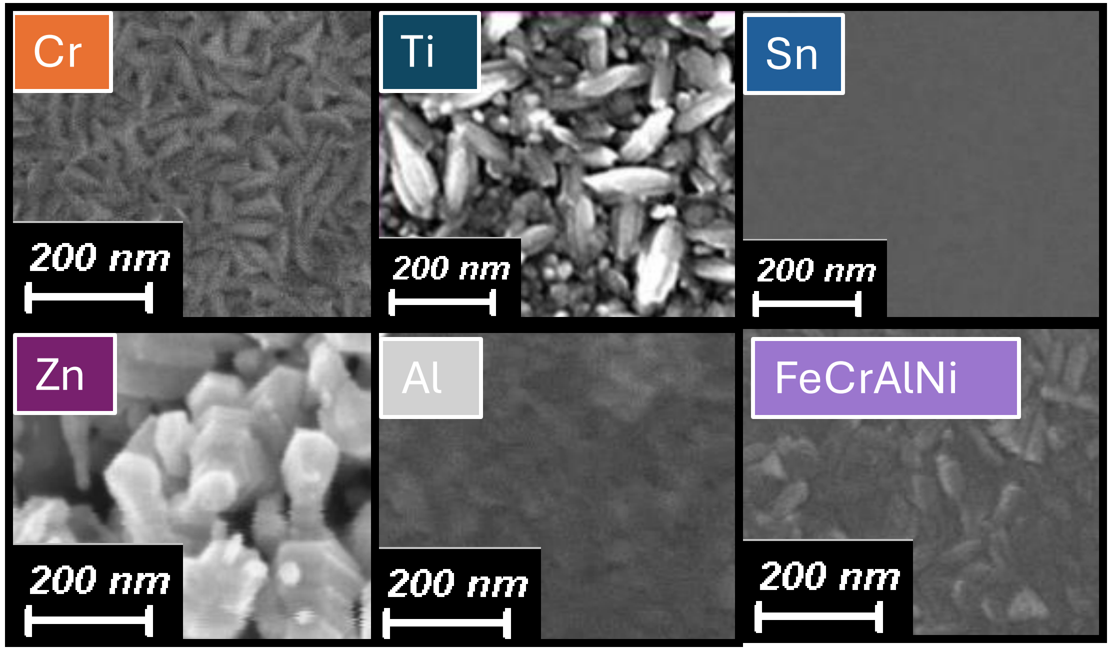
High Power Impulse Magnetron Sputtering (HiPIMS)





- **Pulsed high voltage**
- High fraction of ionized species (> 50%)
- Bias voltage (tunable sputtered ions energy)
- Compact/dense films
- Low deposition rate

Target fabrication @ NanoLab : MS metallic foils



- Interesting for **laser-driven ion acceleration**
- **Alternative/complementary** to **commercial** solid foils

- **Dense** and **compact metallic** films
- **Wide choice** of **metallic materials**
- **Multi-elemental films**
- **Tunable properties** (morphology, density, thickness, composition …)

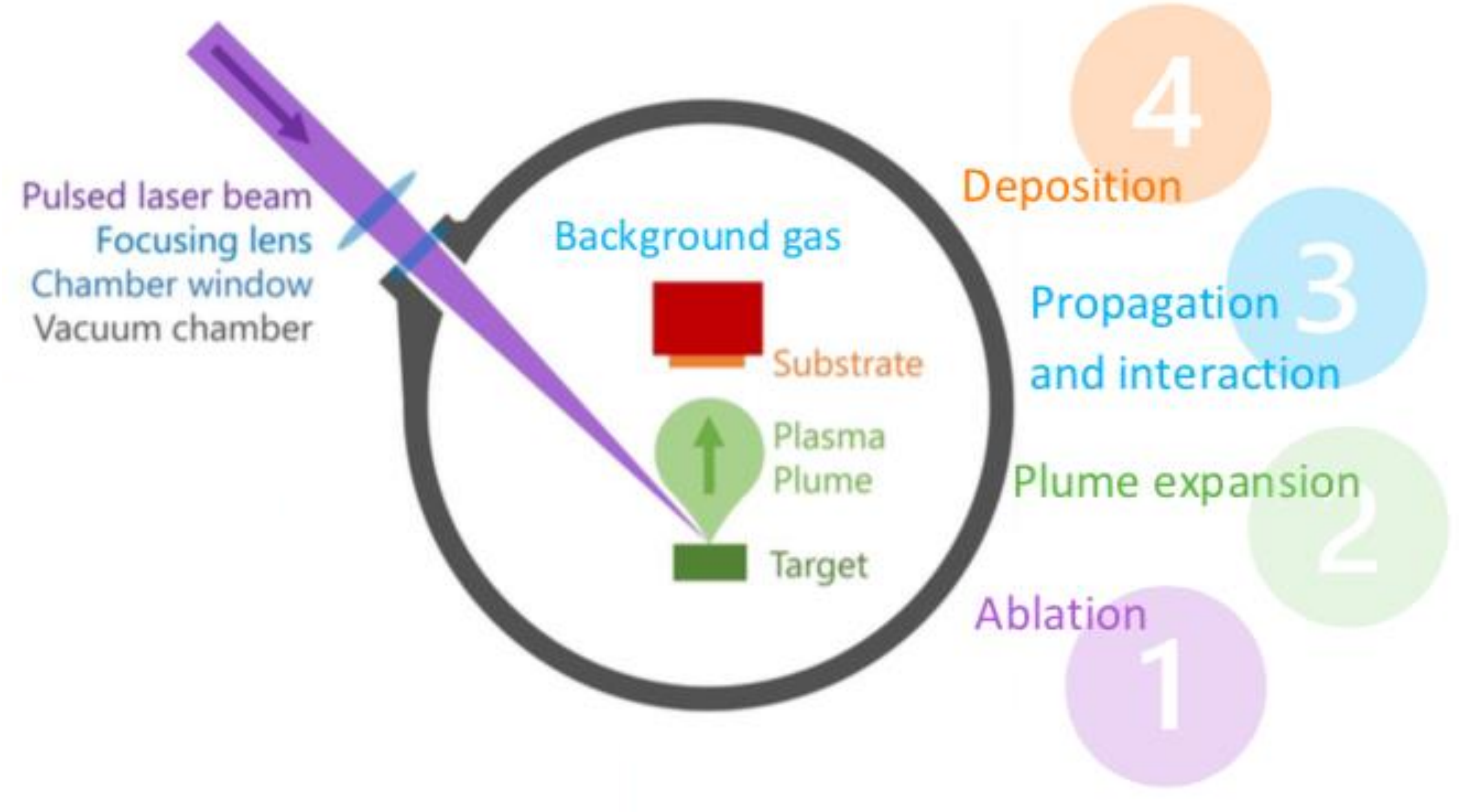
MS deposited foils

- Tunable thickness
- Thickness uniformity
- High shot to shot reproducibility

Commercial foils

- Limited thickness availability
- High thickness uncertainity
- Shot to shot ucertainty

Target fabrication @ NanoLab : Pulsed Laser Deposition (PLD)



- Background gas pressure
- Laser pulse duration
- Target-substrate distance
- Laser fluence

Deposited film properties control

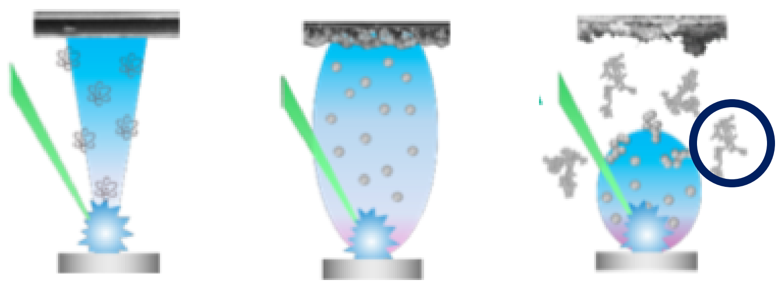
(density, thickness, elemental composition, morphology)

Orecchia D. et al., *Small Structures, 5, 2300560 (2024)*
Maffini A. et al., *Applied Surface Science 599, 153859 (2022)*

Target fabrication @ NanoLab : Pulsed Laser Deposition (PLD)

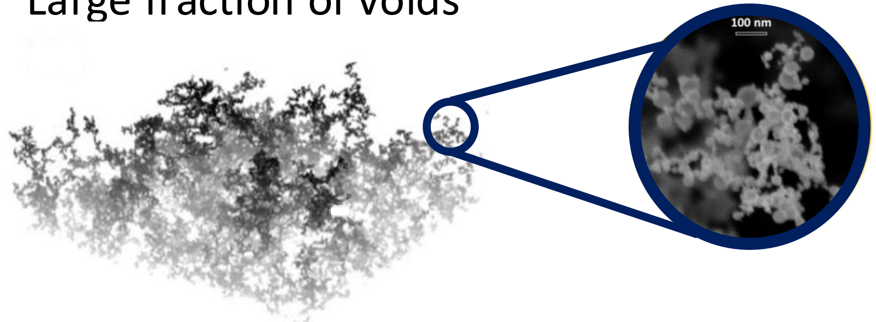
Background pressure → density and morphology

Few Pa → 10s Pa → 100s Pa

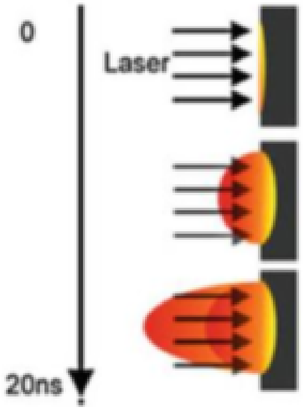


Compact film → **Nanofoam**

- **Nanoparticle-assembled** structures
- Density down to **few mg/cm³**
- Large fraction of voids

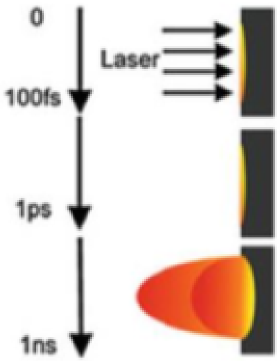


Laser – pulse duration → ablation regimes



ns pulses

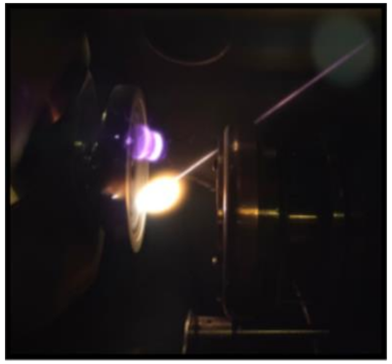
- **Ejection of atoms/ions**
- Suitable for the production of both **compact** and **nanofoam** materials

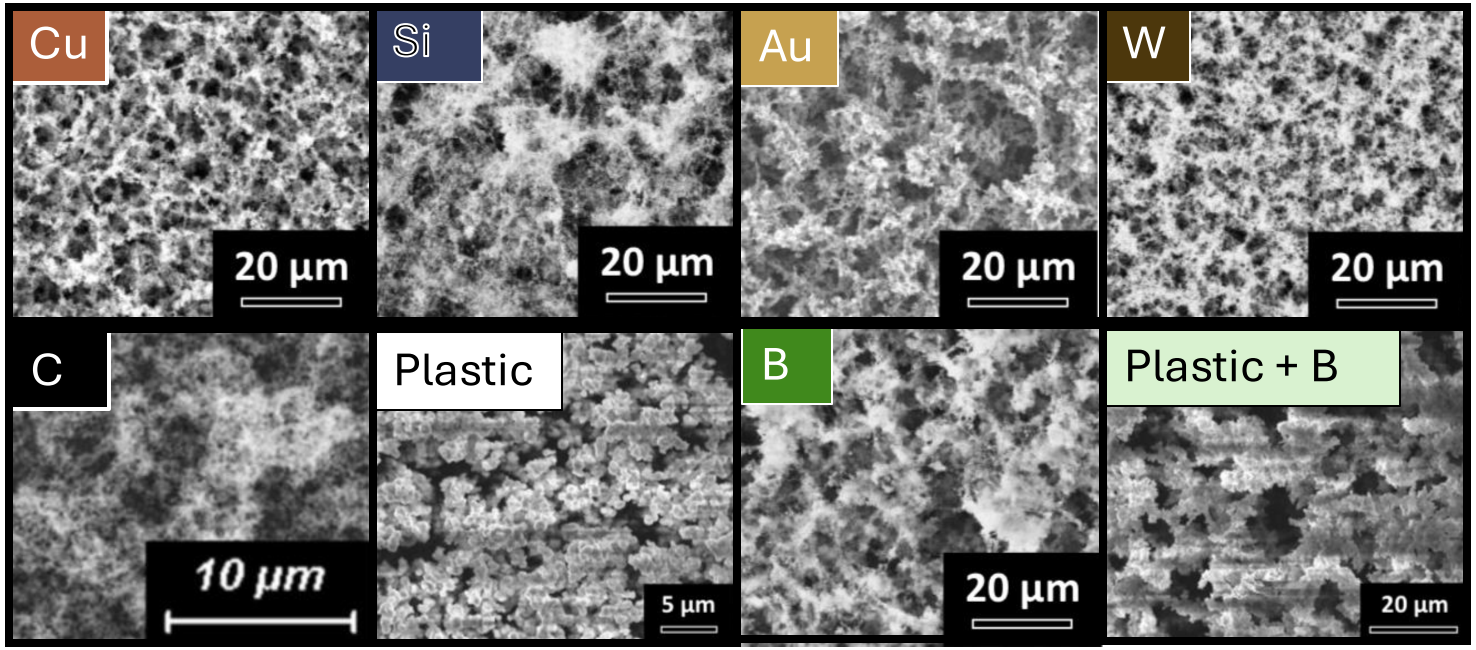


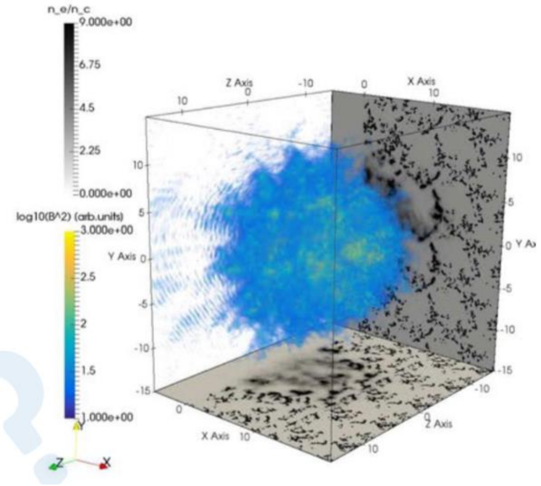
fs pulses

- Direct **ejection of nanoparticles**
- Not suitable for compact films
- **Nanofoams** of a **wide range of materials**

Target fabrication @ NanoLab : PLD nanofoams



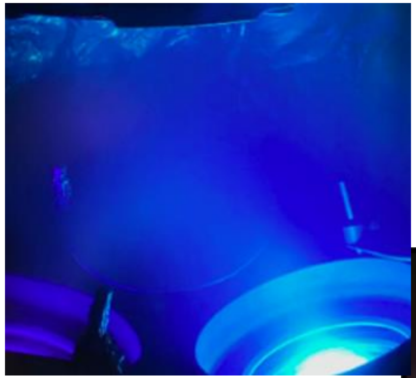




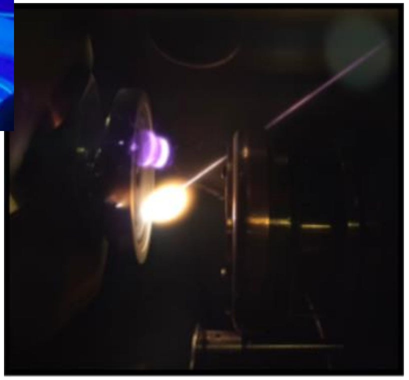
- **Tunable properties** (morphology, density, thickness, composition …)
- High **flexibility** on **materials choice**
- **Multi-elemental** nanofoams
- **Multi-scale structure**

- Density ~ **critical density**
- **Efficient volumetric absorption** of laser energy
- Interesting for **various laser –plasma interaction** processes

PVD targets and Experimental campaigns



Complementary



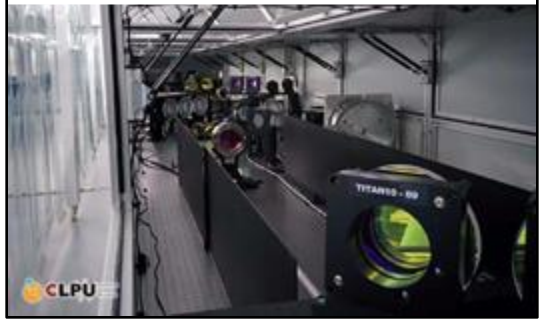
Versatile

Different applications

Tailored target **properties**

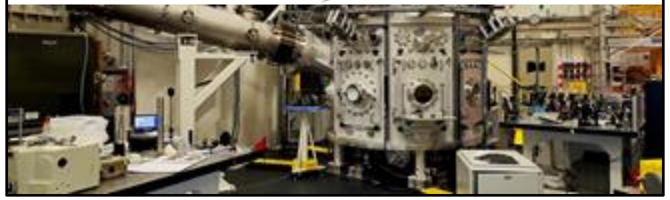
(density, thickness, elemental composition, morphology)

VEGA-3



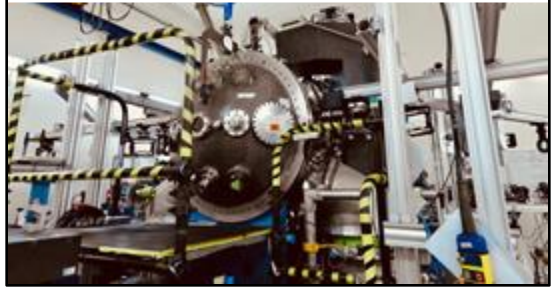
ELI-Beamlines

Apollon laser



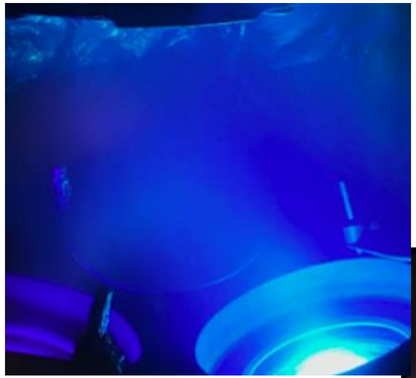
2-3 years

ABC laser

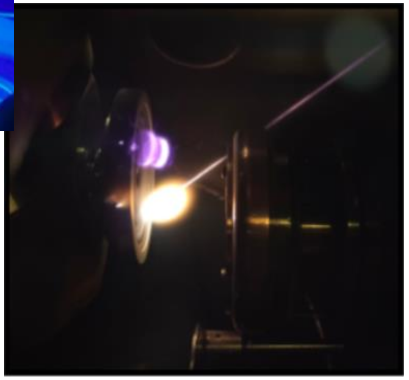


Taranis laser

PVD targets and Experimental campaigns



Complementary



Versatile

Different applications

Tailored target **properties**

(density, thickness, elemental composition, morphology)

VEGA-3 (CLPU)
Laser-driven **proton** and **neutron** sources
2023

ELI-Beamlines (eli)
Proton acceleration for **PIXE** characterization of cultural heritage
2024

Apollon laser (Apollon)
Laser-driven **photon** emission
2024

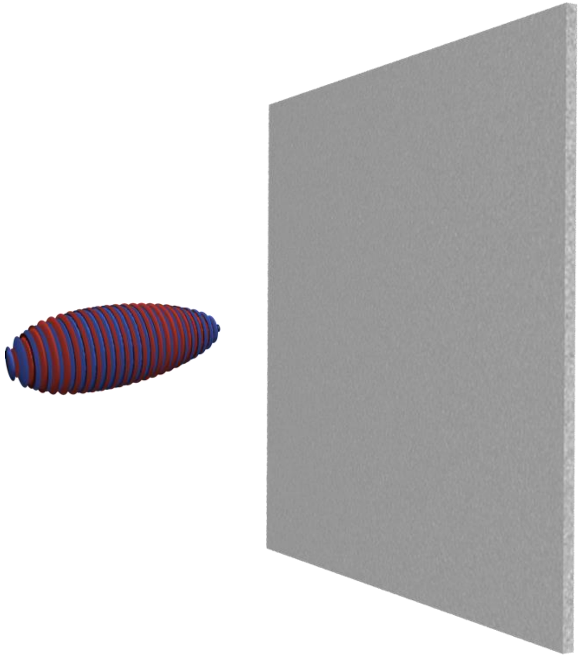
2-3 years

ABC laser (ENEA)
Ablation loadig efficiency of **C nanofoams**
2022

Taranis laser (Queen's University Belfast)
p-^{11}B fusion with **plastic/boron nanofoams**
2023

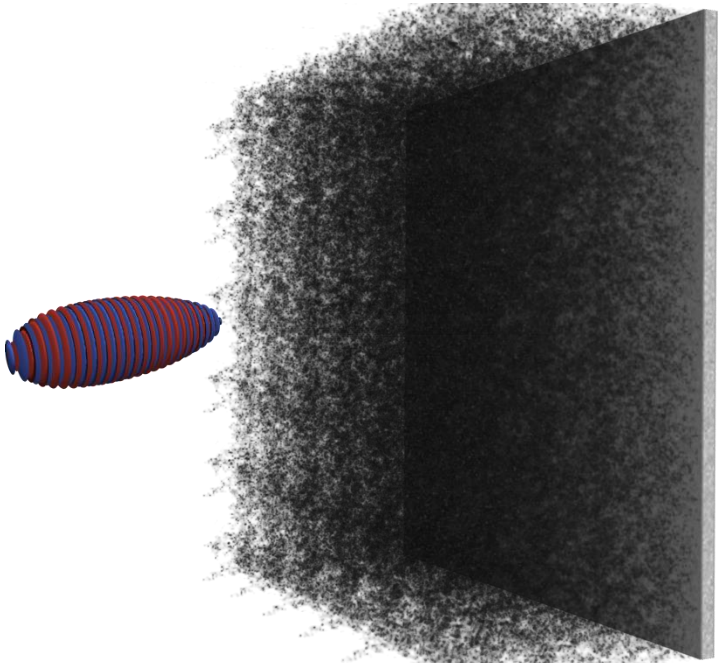
PVD targets @ NanoLab

Single Layer Targets



Thin Magnetron
Sputtered metallic foils

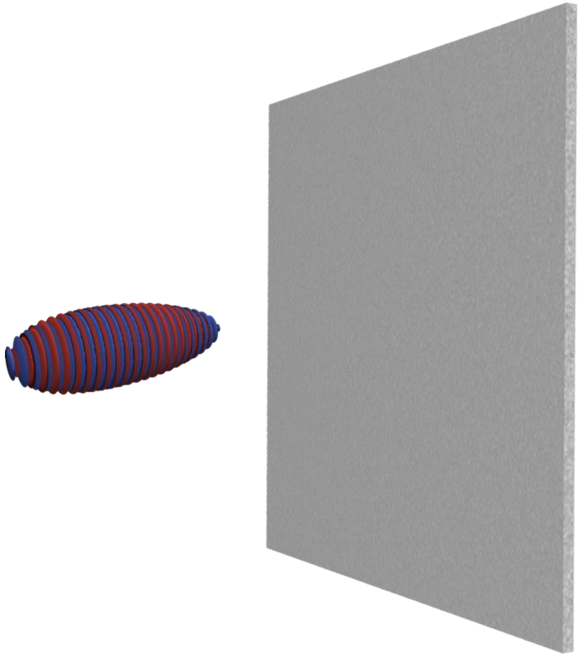
Double Layer Targets (DLTs)



$\sim \mu$m near-critical
C foams

PVD targets @ NanoLab

Single Layer Targets



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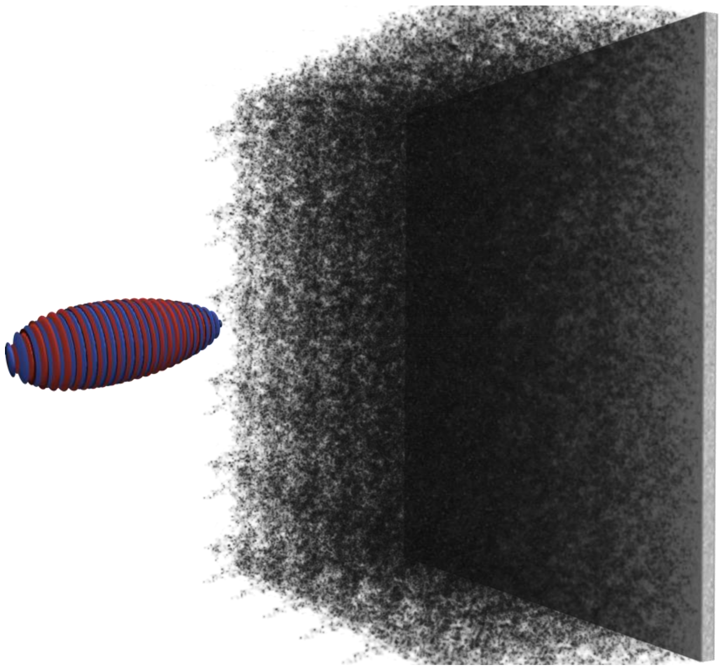

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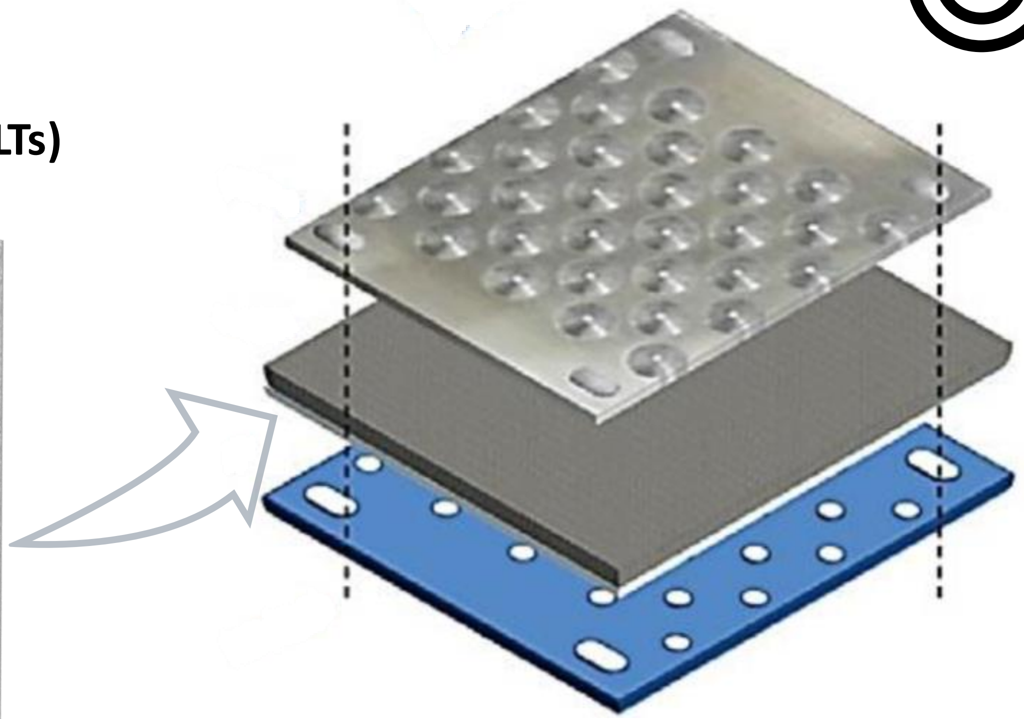
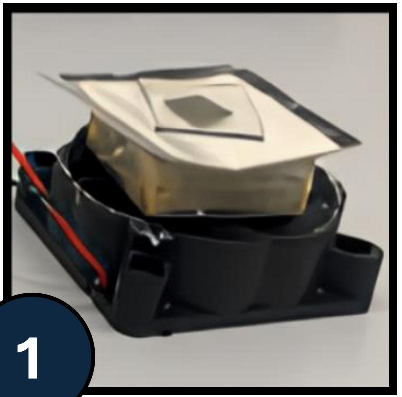


How to make free-standing PVD targets?

PVD targets @ NanoLab

How to make PVD targets free-standing?

Spin-coated soap layer

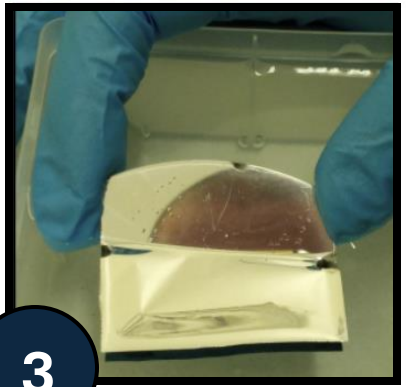


1

DCMS/HiPIMS

2

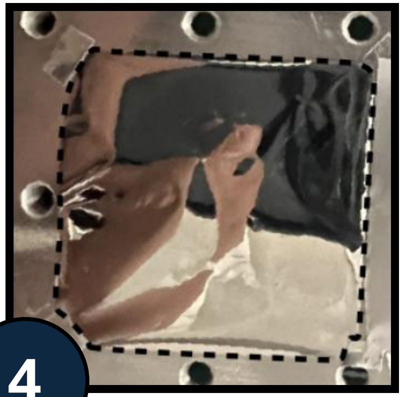
Dissolution



3

Fishing

Single Layer Target



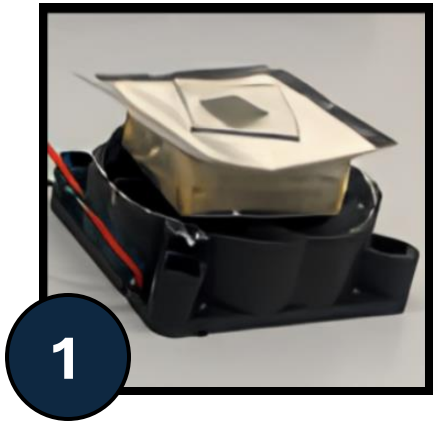
4

- **Materials**:
  Al, Cu, Sn
- **Thicknesses**:
  100s nm – few μm

Maffini A. et al., *European Physical Journal Techn. Instrum., 10, 15 (2023)*

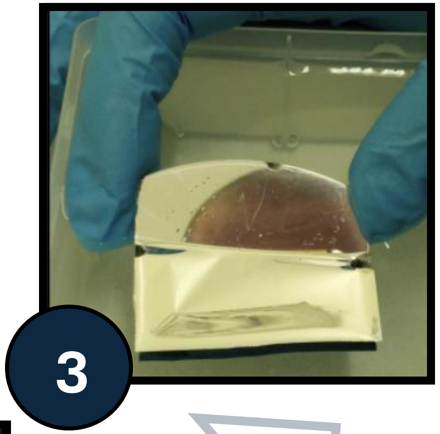
PVD targets @ NanoLab

How to make PVD targets free-standing?



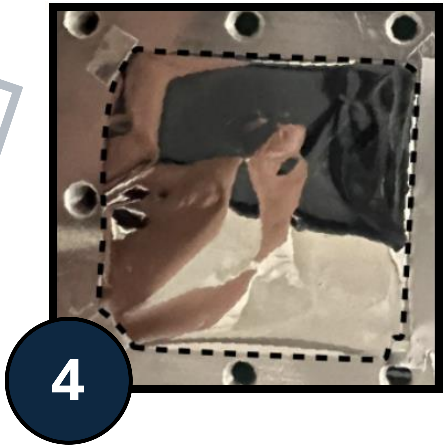
DCMS/HiPIMS

Dissolution



Fishing

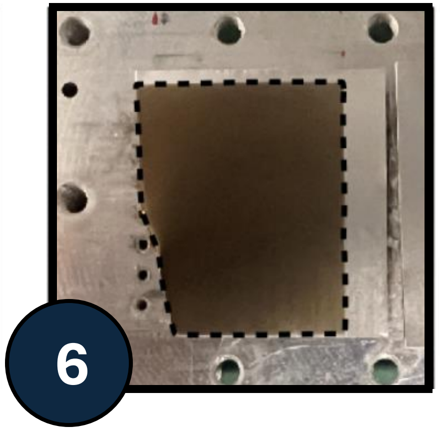
Single Layer Target



- **Materials**:
  Al, Cu, Sn
- **Thicknesses**:
  100s nm – few μm

PLD

Double Layer Target (DLT)



Maffini A. et al., *European Physical Journal Techn. Instrum., 10, 15 (2023)*

PVD targets for laser-driven proton acceleration

VEGA-3 laser parameters

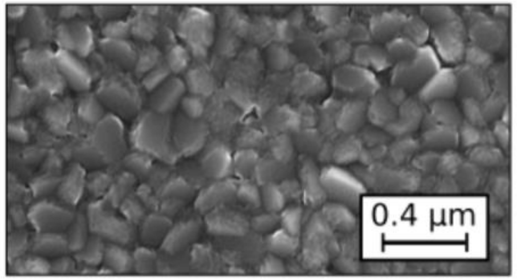
- 30 – 50 fs pulse
- 12 um FWHM
- 4 J in spot
- 1.25 x 10^{20} W/cm^2
- Contrast 10^{-10} – 10^{-5}

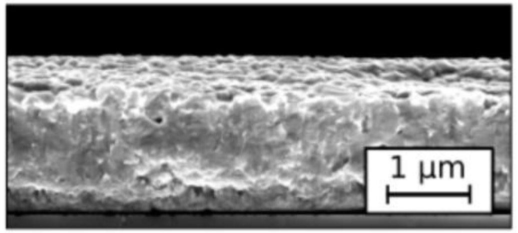
- **MS deposited Al foils** (0.8 – 5 um)
- **Commercial Al foils** (0.75 – 12 um)
- **DLTs**
  - 1.6 um MS deposited Al foil substrates
  - Average carbon foam density 6.4 mg/cm3
  - Carbon foam thickness range 9-54 um

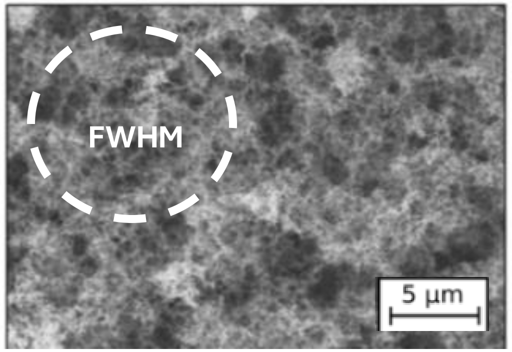
MS deposited Al foils vs **Commercial Al foils**

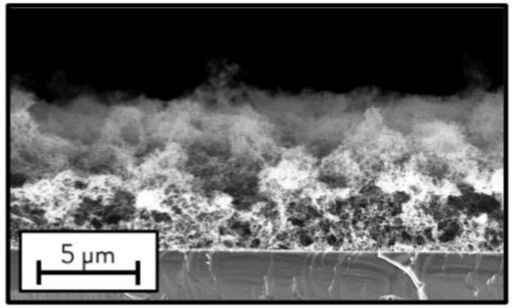
DLTs vs **Commercial Al foils**

DLTs vs **MS deposited Al foils**









Mirani F. et al., addressing the role of advanced targets for enhanced control of laser-driven hadron sources - submitted

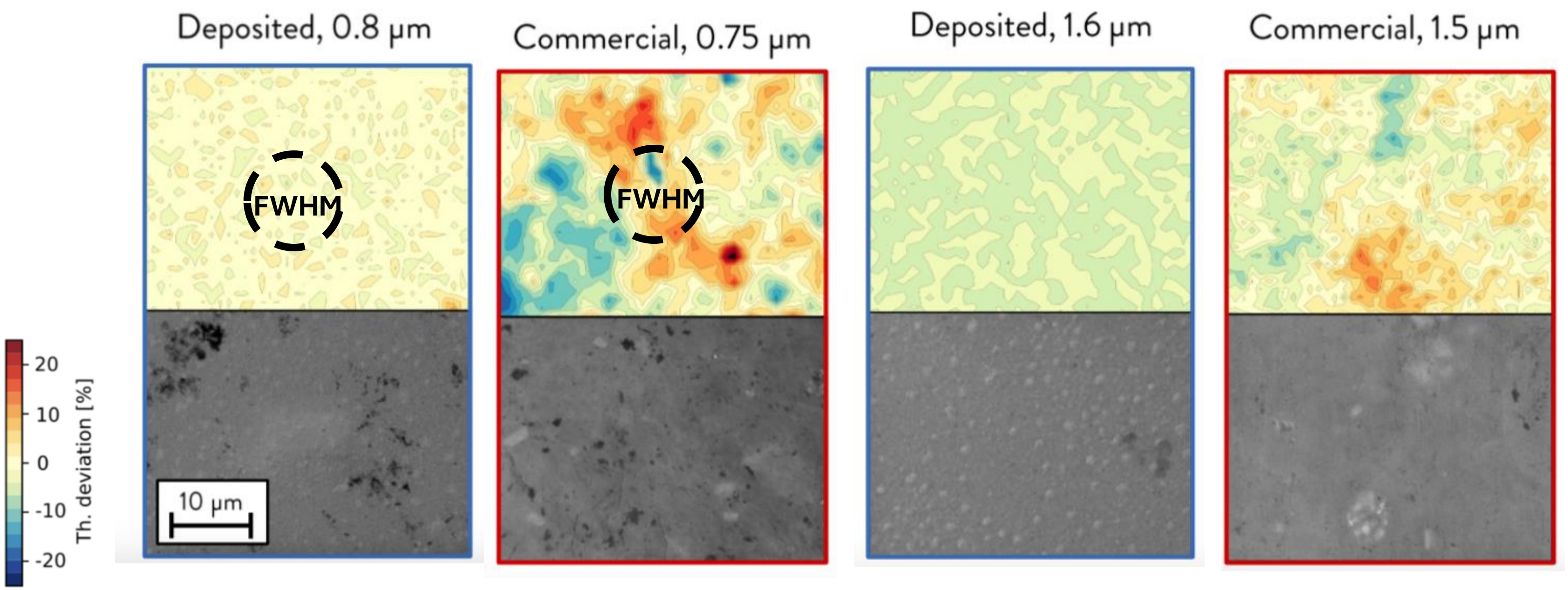
PVD targets for laser-driven proton acceleration

MS deposited Al foils (0.8 – 5 um)

- Thickness non uniformity up to 5 %

Commercial Al foils (0.75 – 12 um)

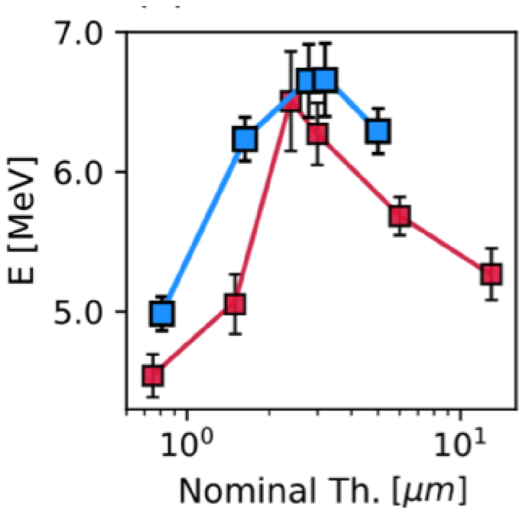
- Thickness non uniformity up to 25%

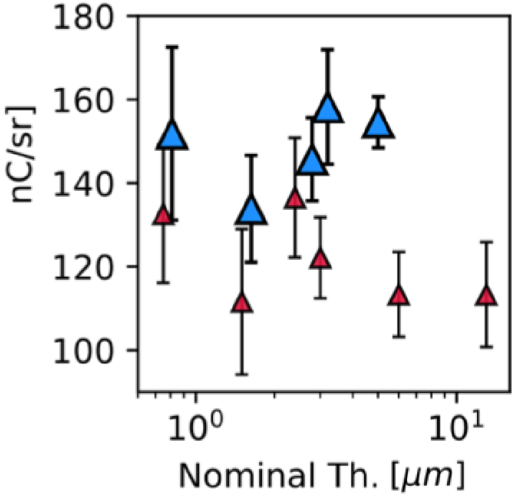


Thickness uniformity determined via EDX maps and nominal thickness of the film

Inhomogeneities impact proton acceleration

PVD targets for laser-driven proton acceleration





MS deposited Al foils vs **Commercial Al foils**

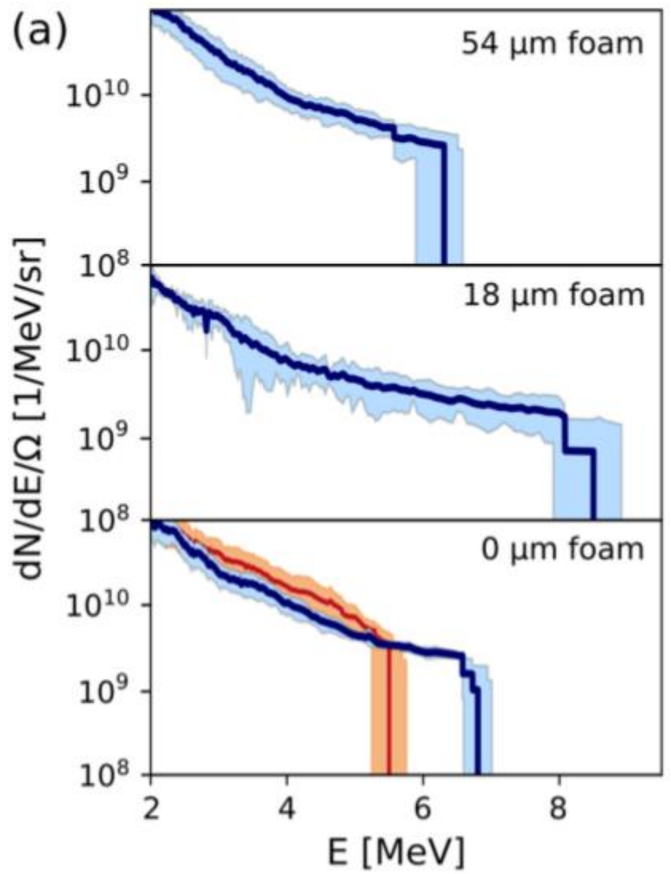
MS targets targets allow for:

- ✓ **Higher energies** (up to 1.5 MeV)
- ✓ **Lower uncertainties** on maximum energies
- ✓ Greater number of **accelerated ions** (up to 30%)

- Improved **thickness uniformity**
- Improved **surface planarity**
- **H contamination** due to residues of soap

PVD targets for laser-driven proton acceleration

DLTs vs **Commercial Al foils** and **MS deposited Al foils**



1.6 um MS substrate with foam
1.5 um commercial substrate

DLTs allow for:

- ✓ Enhancement with respect to both **Commercial Al foils** and **MS deposited Al foils**
- ✓ **Enhancement up to 50%** of maximum energy compared to **Commercial Al foils**

- **Nanofoams damage** due to laser interaction
- No shot to shot reproducibility

Poster session: *Investigation of nanofoam damage after laser interaction with double layer targets*

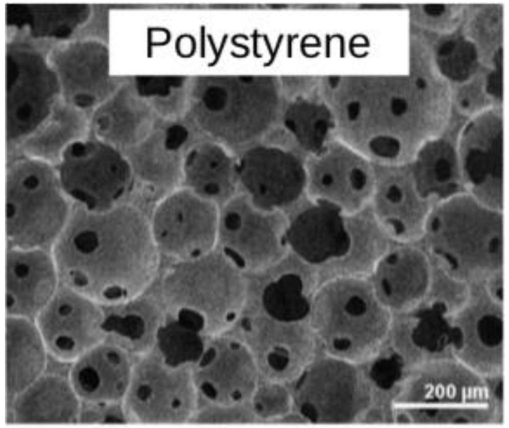
Ablation loading efficiency of PLD C nanofoams

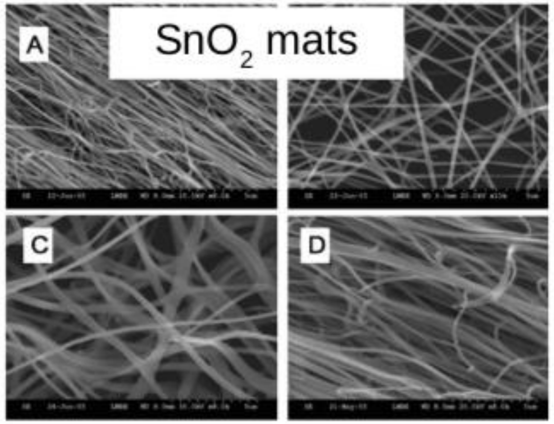
Foams in Inertial Confinement Fusion **(ICF)**

- **Smooth** laser **inhomogeneities**
- **Improve absorption**
- **Enhance ablation loading**

Conventional foams

- plastics, oxides, …
- Microstructure with voids and solids in the **10-100 um range**



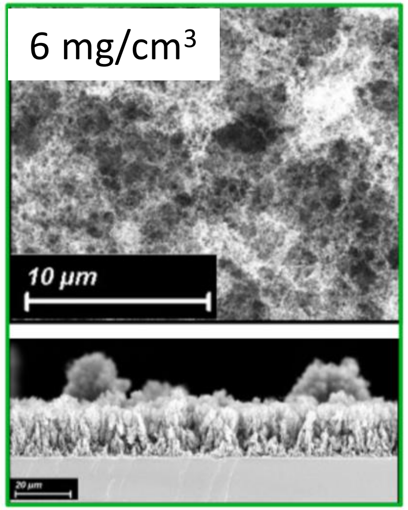


K. Nagai, et al., *Physics of Plasmas* **25**, 030501 (2018)

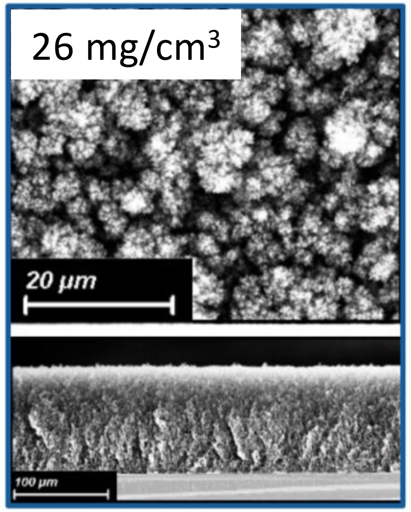
Can our foams be interesting?

- C nanofoams
- **Multiscale structure** with micrometric aggregates and nanometric constituents

Fractal - like



Tree - like

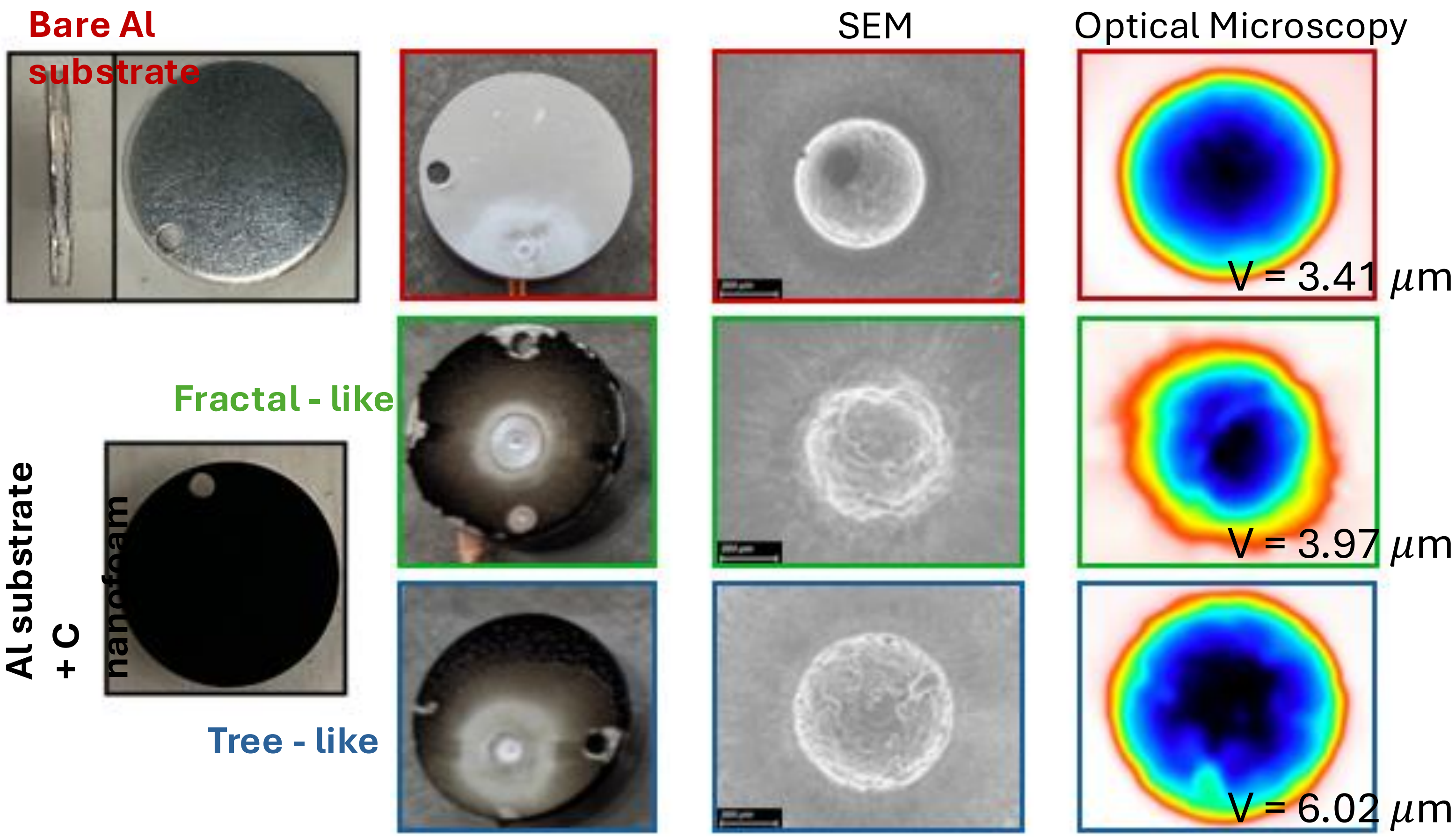


Ablation loading efficiency of PLD C nanofoams

- PLD – **C nanofoam** tested in **ICF** relevant conditions for the first time

ABC laser parameters

- 3 ns pulse
- Wavelength 1054 nm
- 40 J
- 10^{14} W/cm^2



- **Enhanced ablation loading** efficiency with **nanofoams**
- **Foam characteristics** play a crucial role

Cipriani. et al., Ablation loading efficiency of carbon nano-structured foams produced with the Pulsed Laser Deposition technique – in preparation

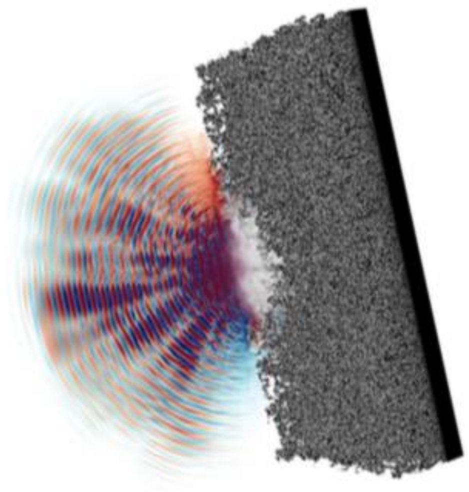
Conclusions and future perspectives

- **MS** and **PLD** allow for the production of **advanced nanostructured solid targets** with **finely tunable and controlled properties**
- Successful employment of **PVD targets** in **different** laser – plasma interaction **experiments**
- **Tailoring** of **target properties** allows for the **control** of **interaction**

- **Optimize the overall target desing**
- Understand the effect of solid targets characteristics on laser interaction
- Understand nanofoam damage mechnaisms

- **extend the avilable range of parameters**
- New composition, thicknesses and densities
- Free – standing nanofoams

- **New experimental campaigns & numerical simulation**



Thank you for your attention !

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