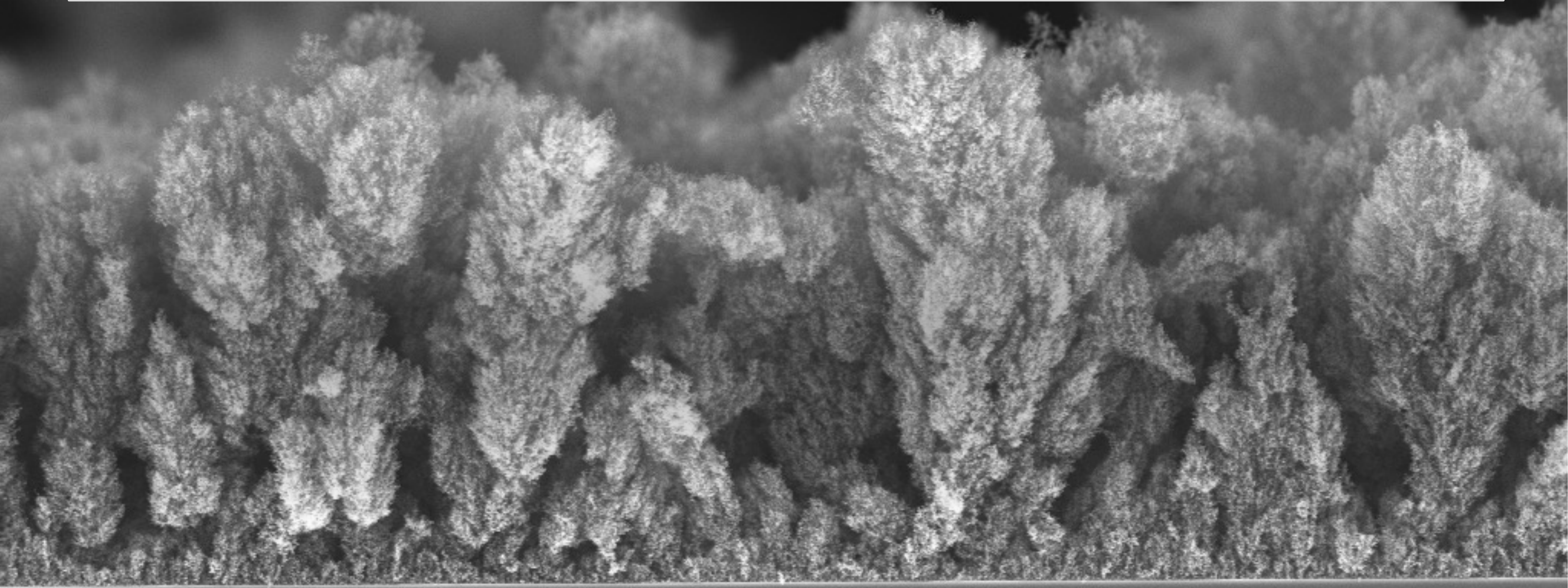
Pulsed Laser Deposition for the synthesis of nano-structured materials for high-power laser experiments



WORKSHOP ON MICRO- AND NANO-STRUCTURED MATERIALS FOR EXPERIMENTS WITH HIGH-POWER LASERS

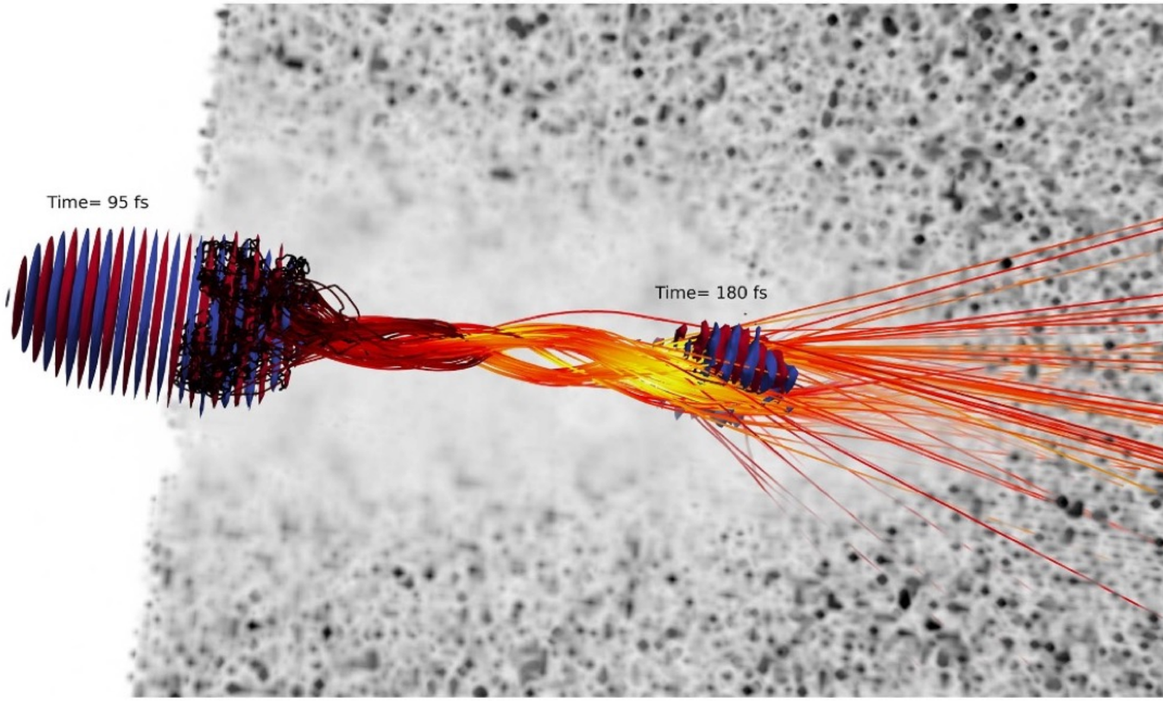
Laserlab Europe

Maria Sole Galli De Magistris

12th June 2026, Frascati

Foams for high-power lasers experiments

Micro- and **nano-structured** materials enable efficient **control** of laser-plasma **interactions** and open pathways to a wide range of **applications**



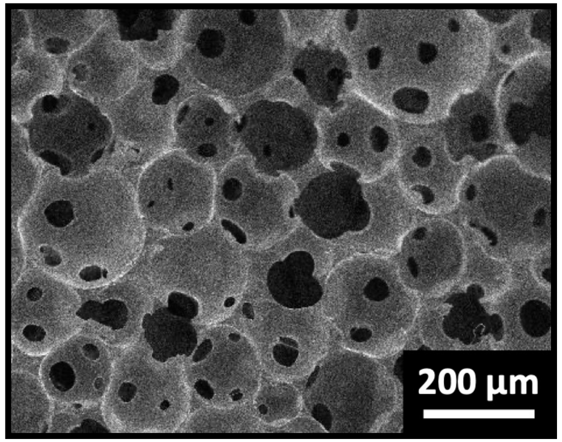
Porous low-density materials (**foams**) enable

- **Near-critical** density
- Efficient **volumetric** laser energy absorption
- **Enhanced** laser-target coupling

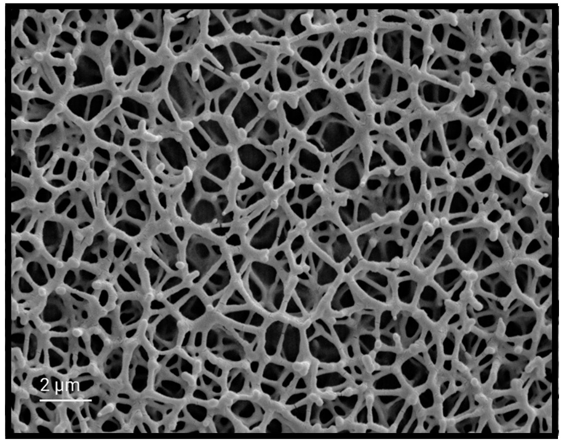
Synthesis methods

- Morphology
- Density
- Composition

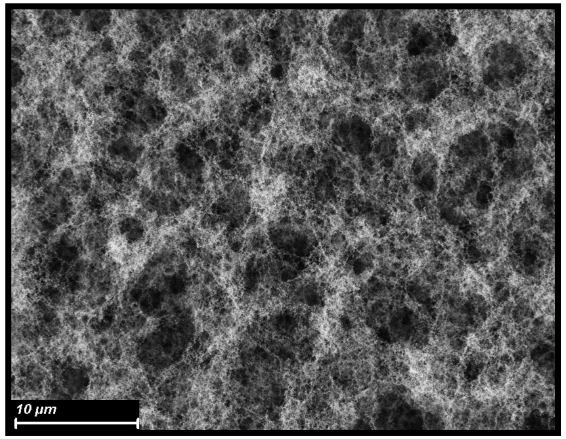
Chemical



Additive



Physical



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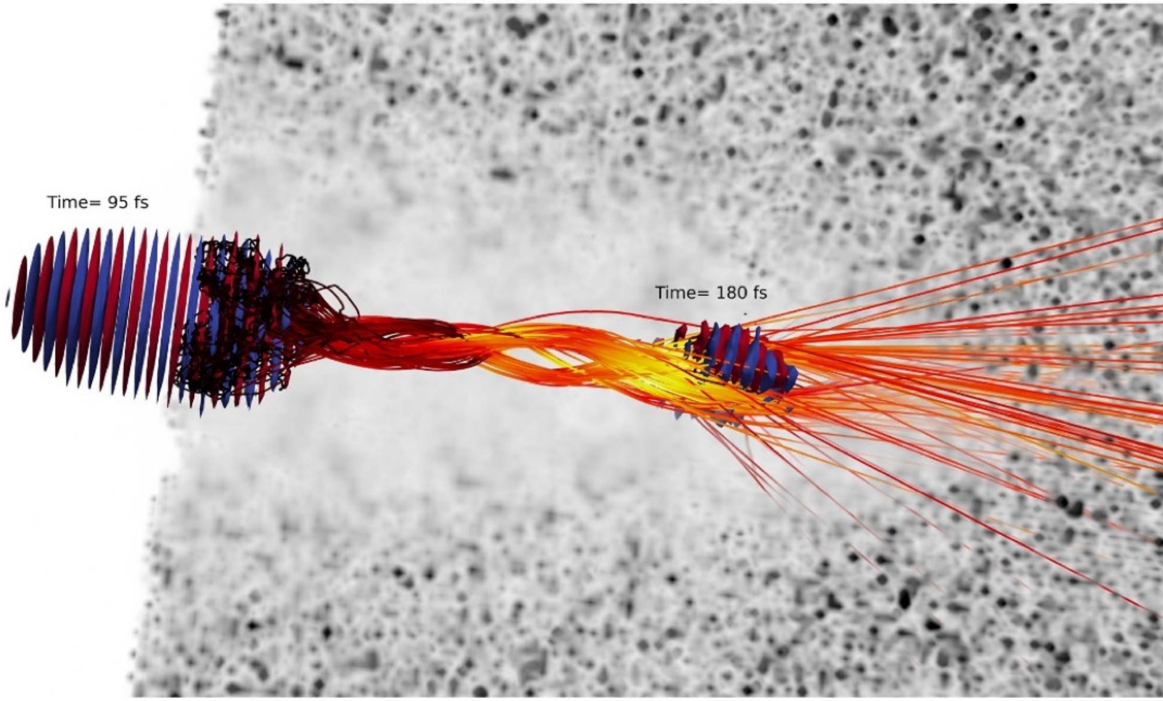
Pulsed Laser Deposition (PLD) offers **tailored control** over critical laser-plasma **parameters**

Francesco Mirani's talk @ DDFIW "numerical and experimental activities on nanostructured carbon foams for Inertial Confinement Fusion"



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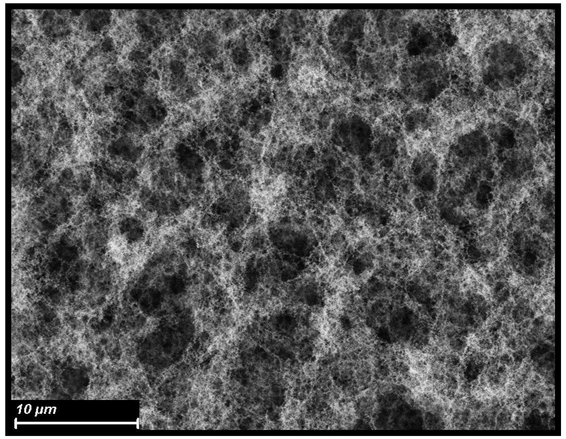

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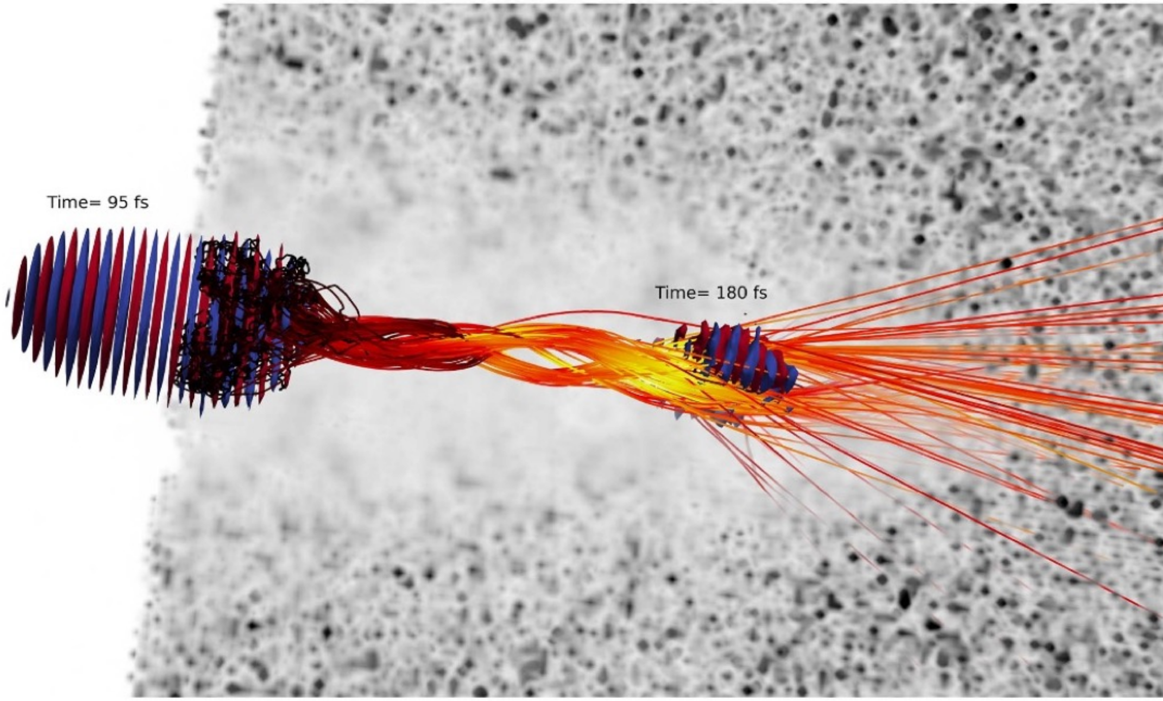

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Content of the presentation

- How does PLD works
- Characteristics of PLD - targets
- Examples of applications

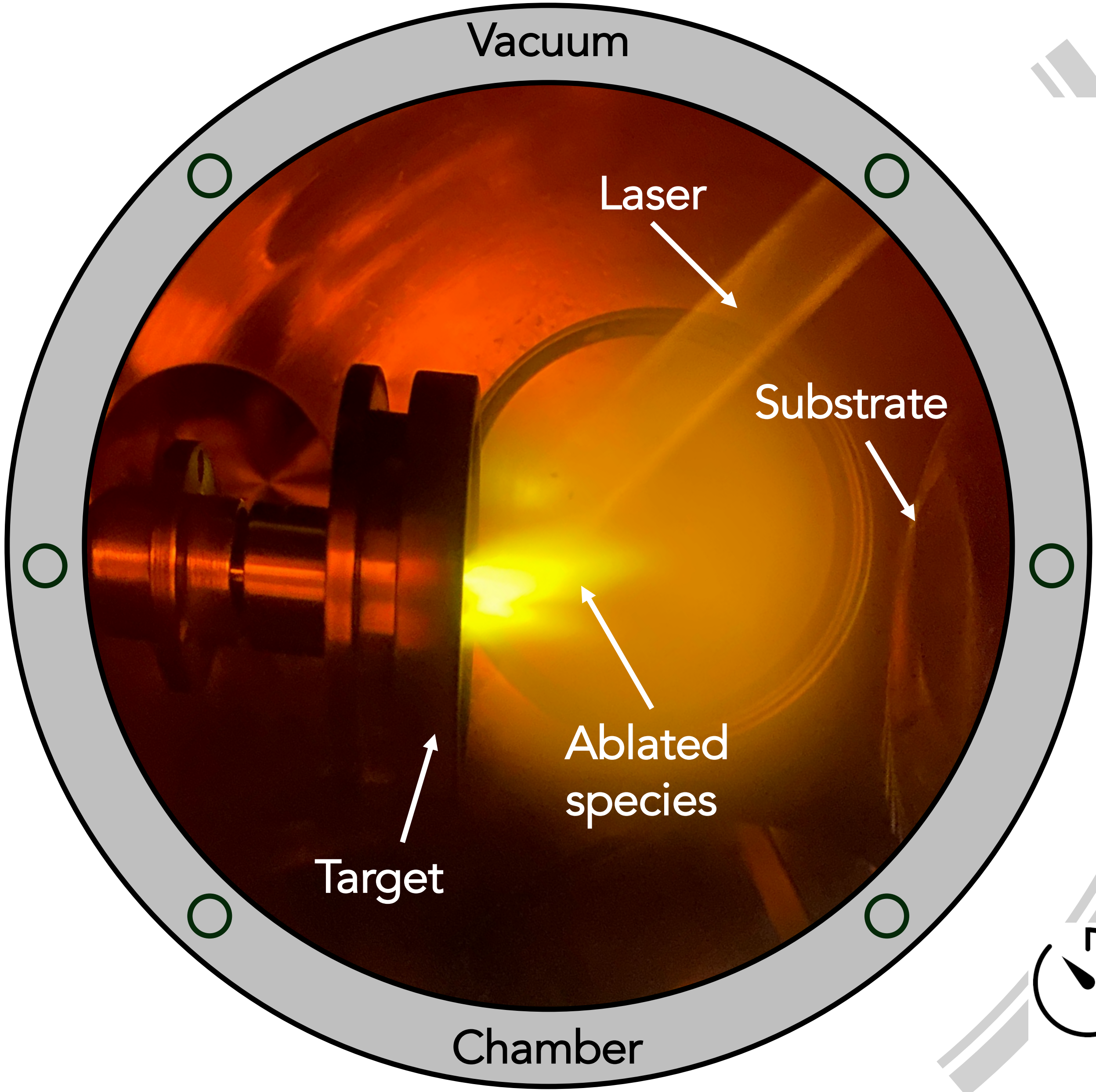
Pulsed Laser Deposition (PLD): a versatile technique

Many degrees of freedom

Complex, non-linear processes

Interplay between process parameter

Control & tunability



Working gas

- Pressure
- Composition (Ar, N_2, mix, …)

Laser

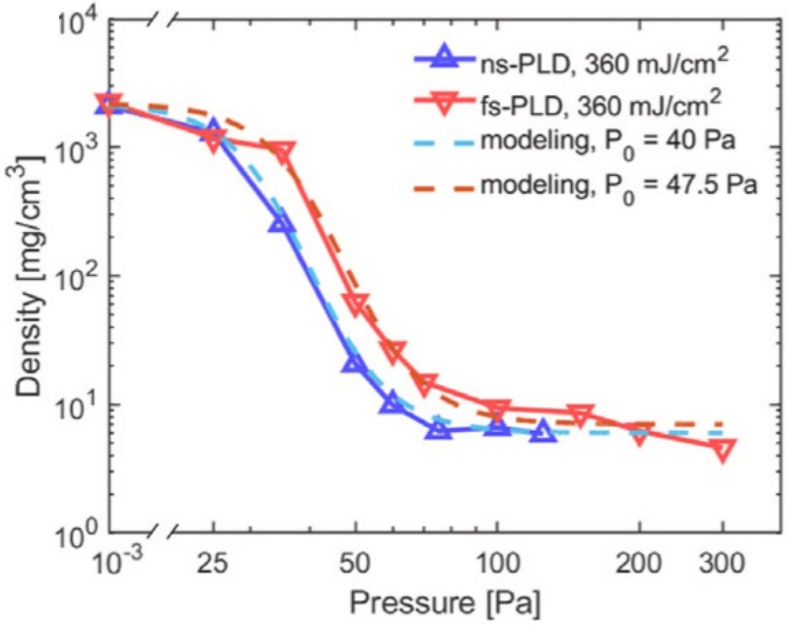
- Pulse duration (ns, fs)
- Fluence
- Wavelength

Target-to-substrate distance

Deposition time

Tuning of density and morphology

Carbon density vs pressure



Maffini A. et al., *Applied Surface Science 599, 153859 (2022)*

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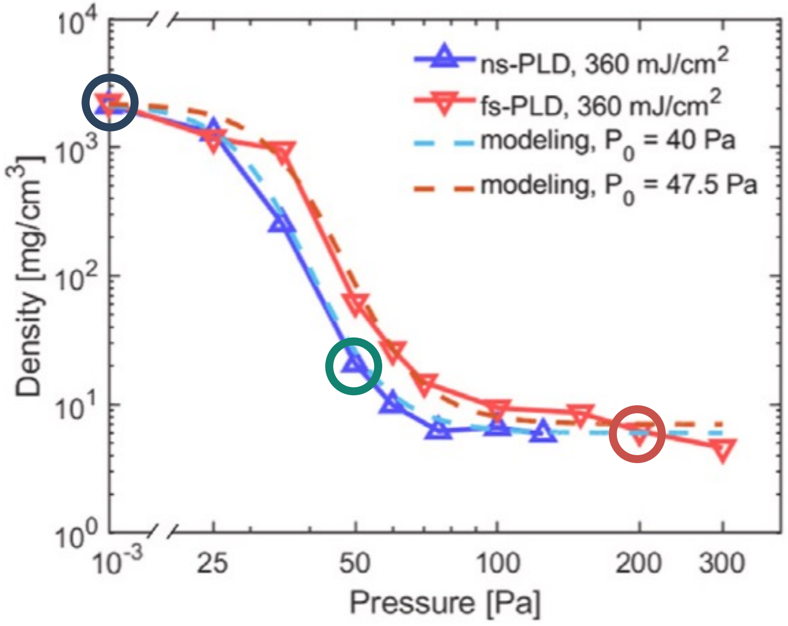

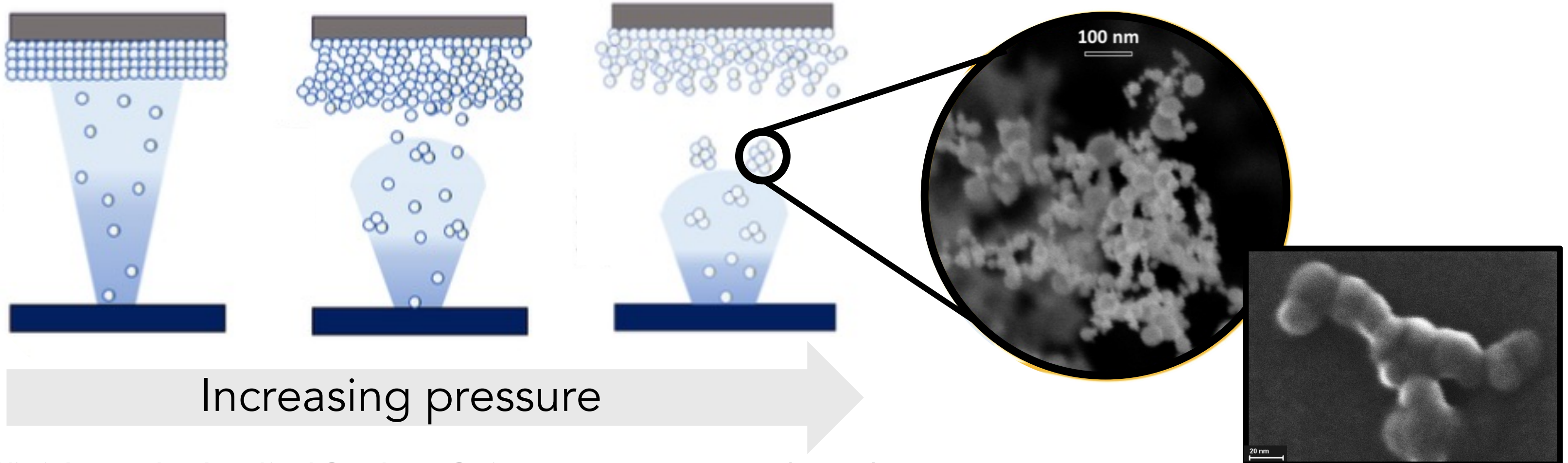

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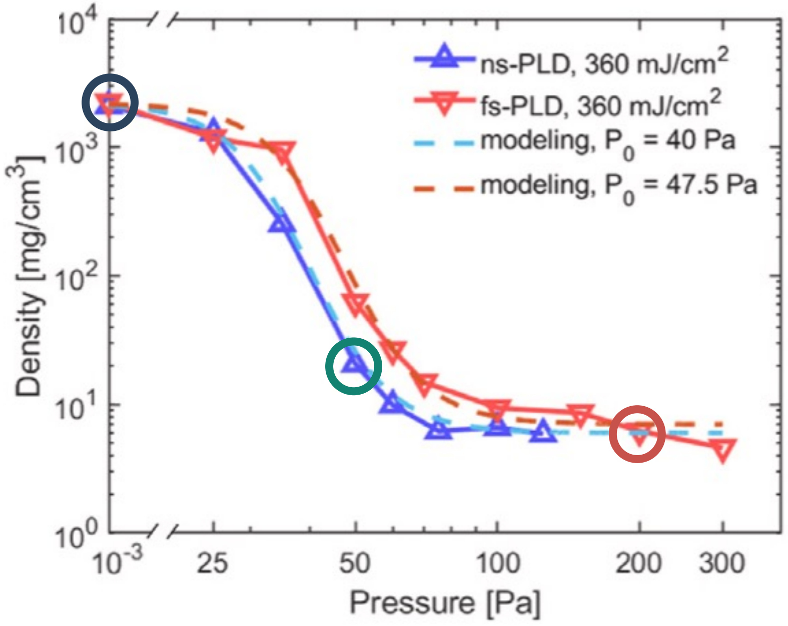
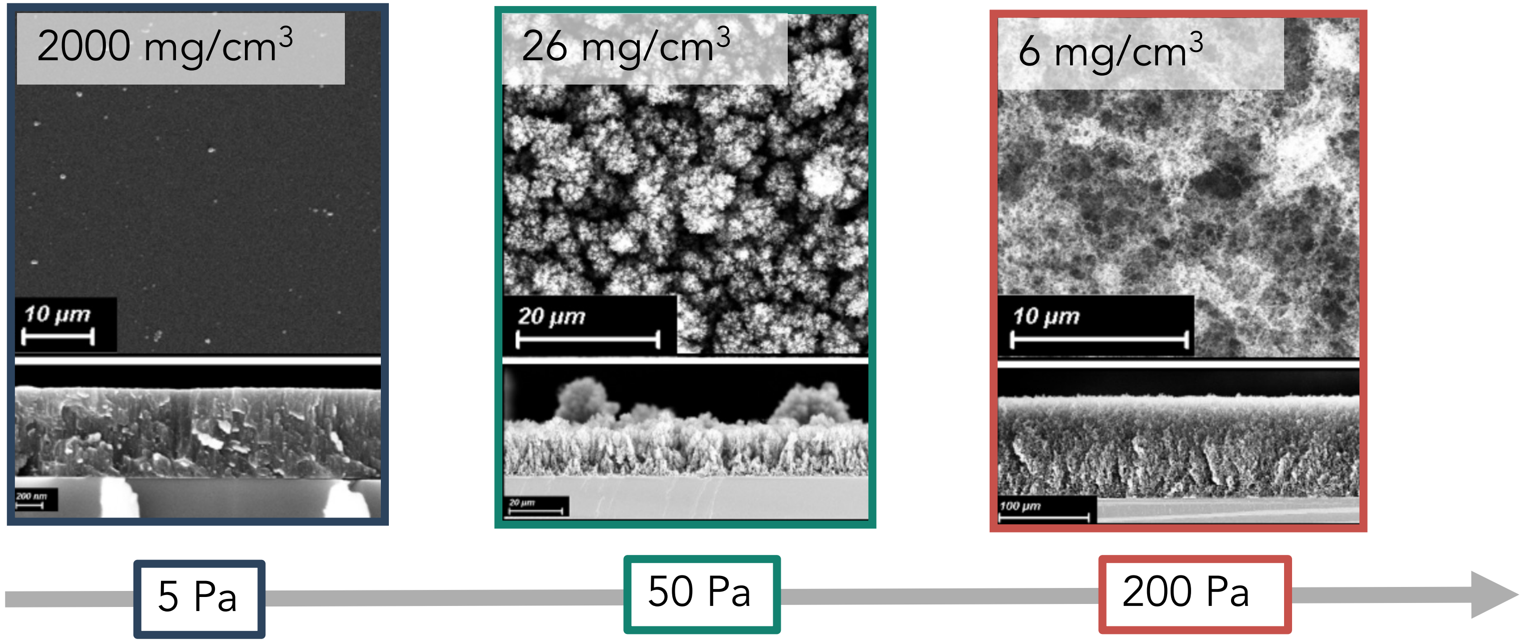
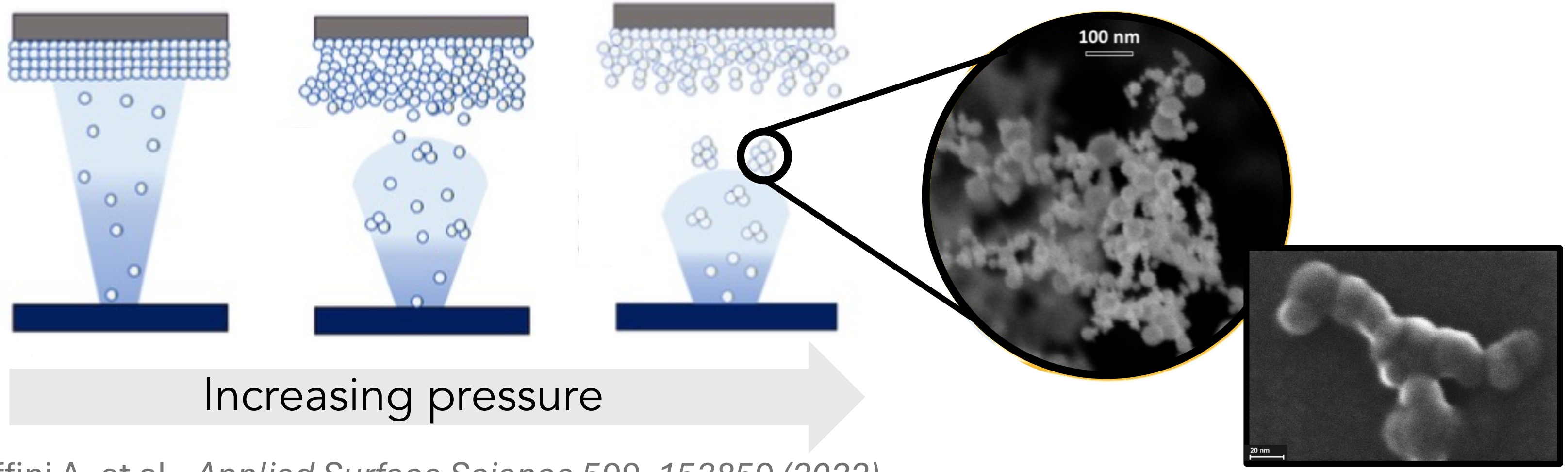


Compact/ nanostructured film

Tree – like morphology

Web – like morphology





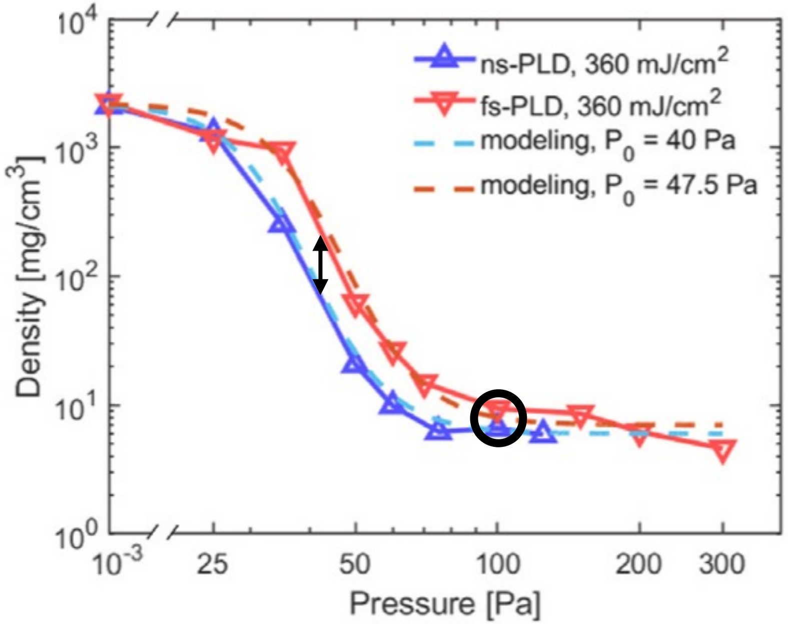
Nanofoam

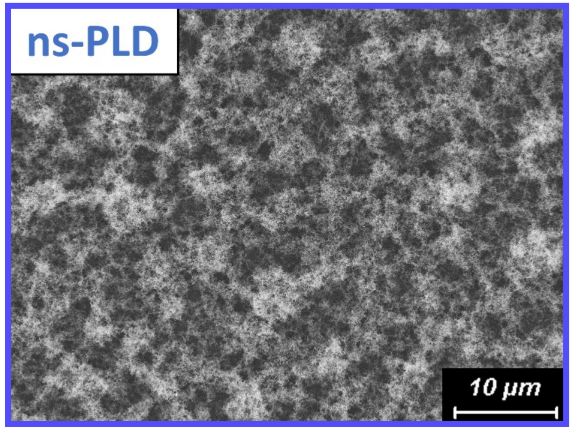
- Multi-scale structure
- Micrometric aggregates of nanoparticles
- Highly porous and disordered network
- Densities down to to few mg/cm^3

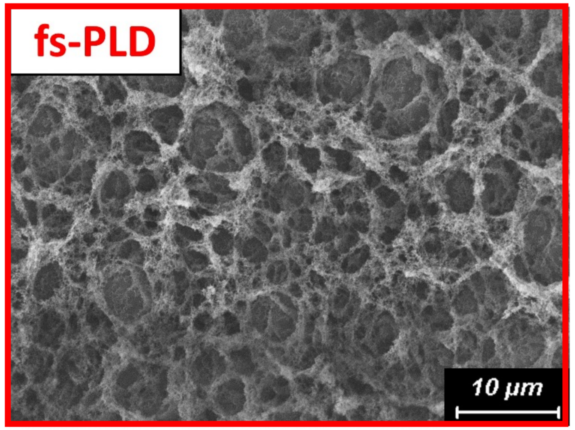
Maffini A. et al., *Applied Surface Science 599, 153859 (2022)*

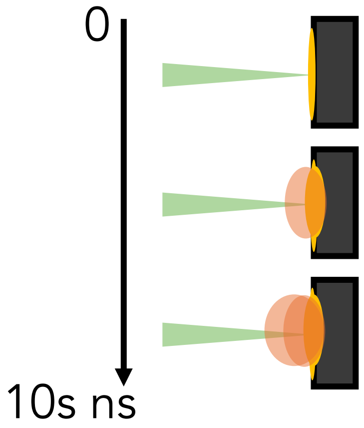
Tuning of density and morphology

Carbon density vs pulse duration

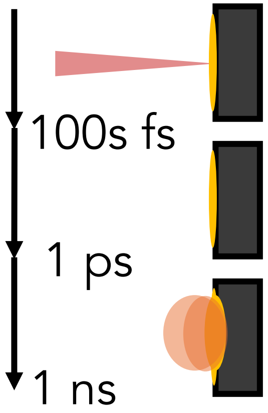








- **Heating** and **vaporization** of the target material
- Ejection of **atoms/ions**
- Gas-mediated aggregation

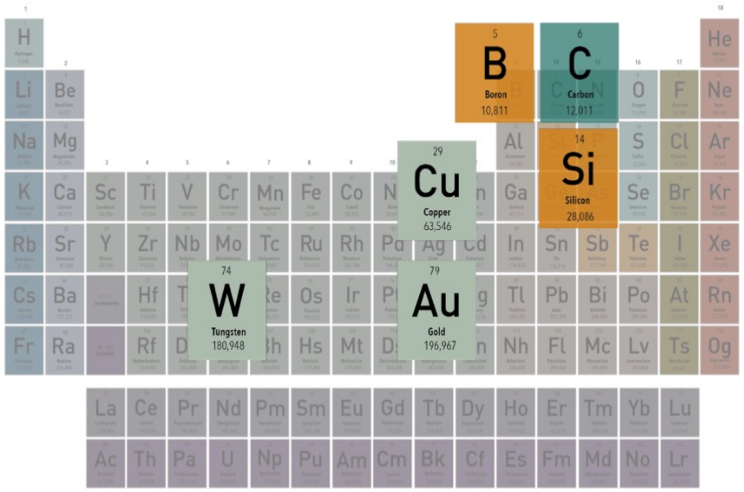


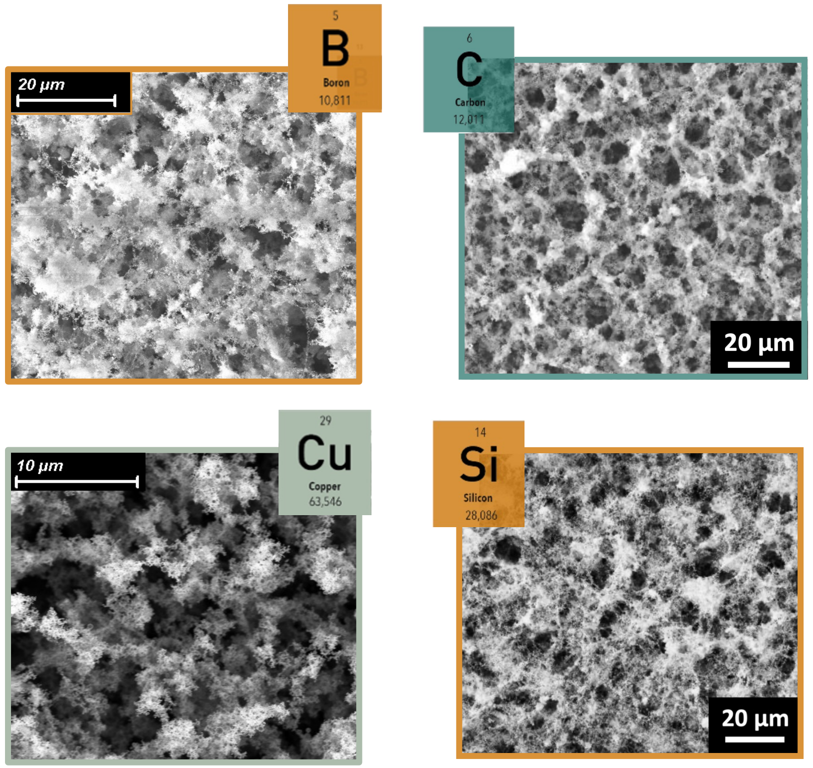
- **Electronic ablation** mechanism
- **Direct ejection** of **nanoparticles**
- **Mixed morphology**

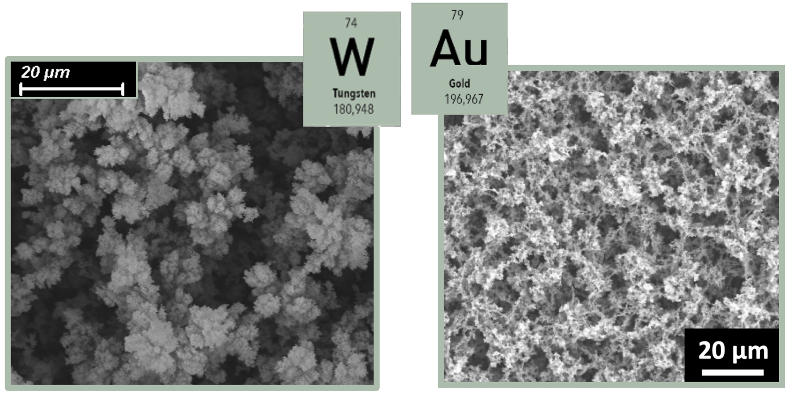
Maffini A. et al., Applied Surface Science 599, 153859 (2022)

Tuning of chemical composition

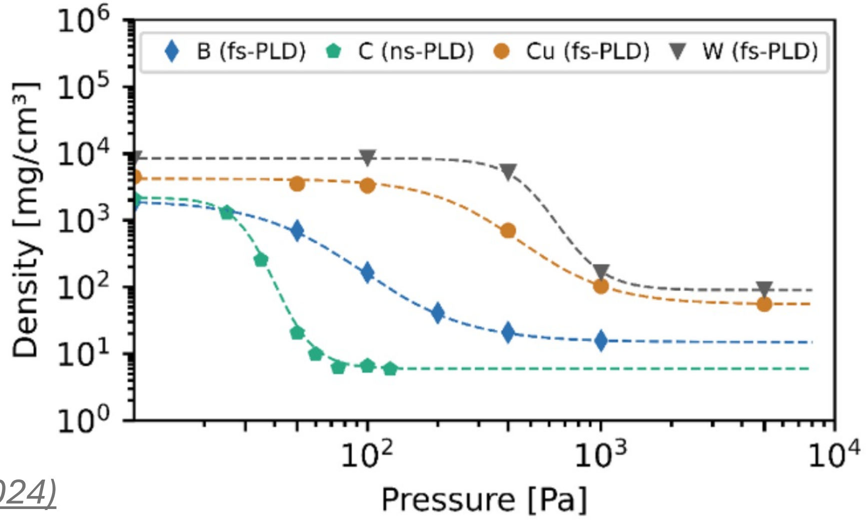
Works with very **different elements**







Same morphology &
density **evolution**



Stoichiometric deposition (from composite targets)

Sequential depositions

Simultaneous depositions

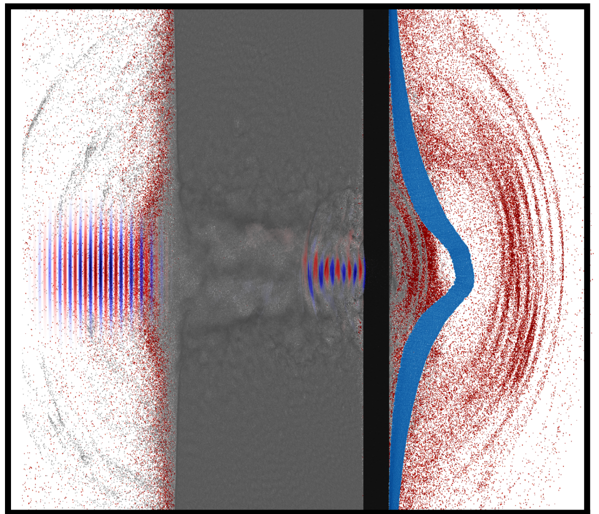
Works with **any kind of substrate**

Engineered targets for **different** laser-plasma interaction **experiments**

Orecchia D. et al., *Small Structures, 5, 2300560 (2024)*

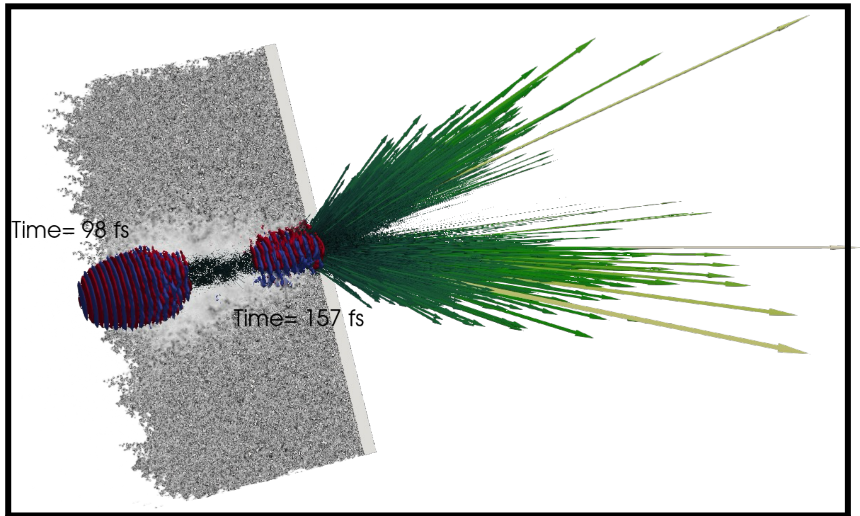
Interaction of high power-lasers with PLD targets

Proton acceleration



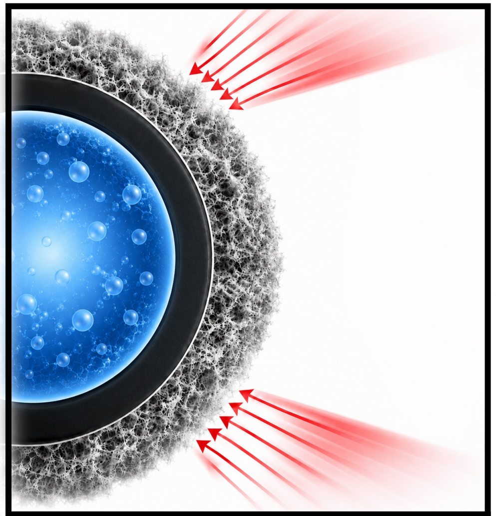
30-180 fs | 10^{18} – 10^{20} W/cm^2

γ photons generation



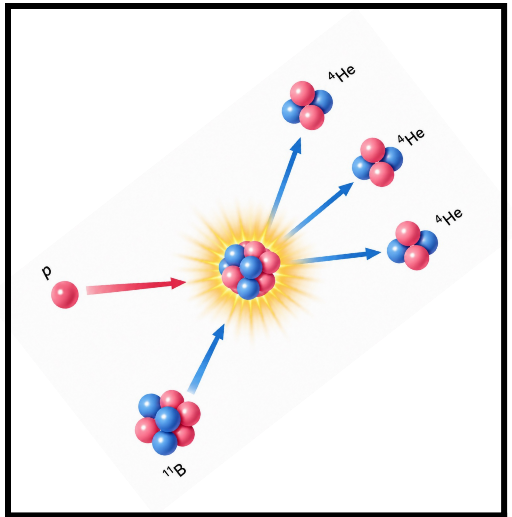
23 fs | 10^{21} W/cm^2

Inertial Confinement Fusion (ICF)



3 ns | 10^{14} W/cm^2

p-^{11}B



800 fs | 10^{19} W/cm^2

Tailoring C nanofoam properties

Sequential deposition of different materials

Co-deposition of B and plastics

A. Maffini et al., Plasma Physics and Controlled Fusion, 68, 035007 (2026)

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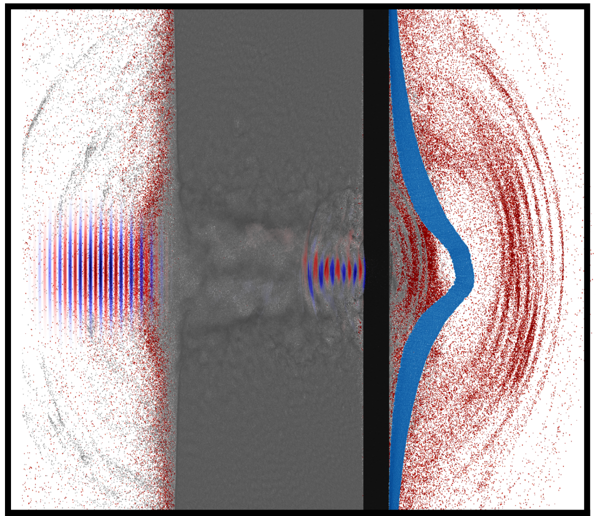

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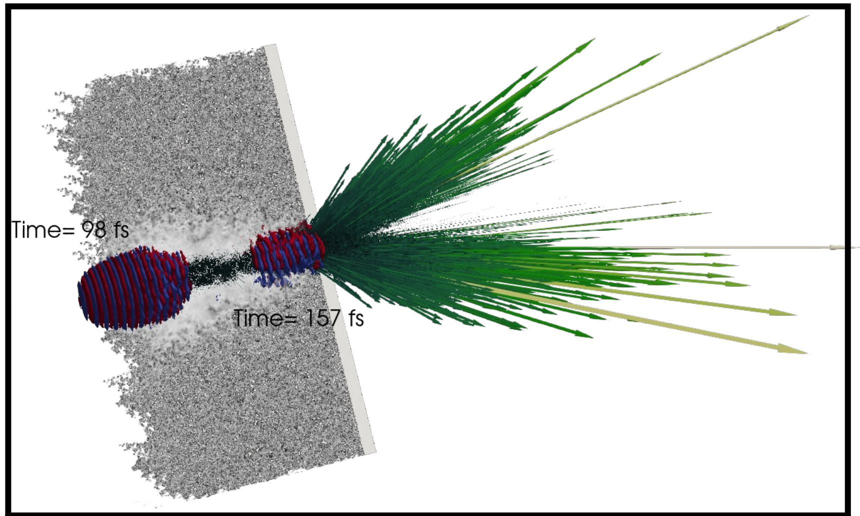

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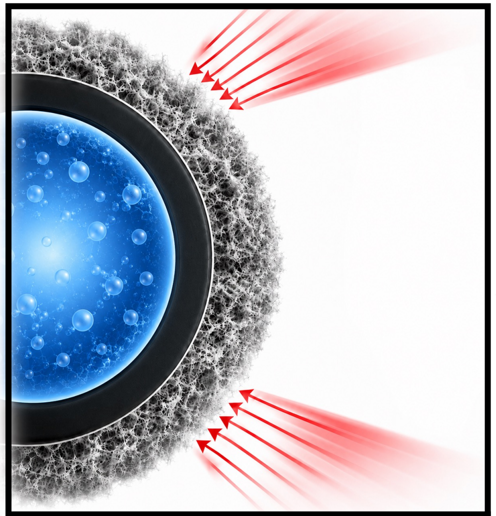

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C nanofoam-based targets for enhanced TNSA

I. Prencipe et al., New Journal of Physics, 23 093015 (2021)

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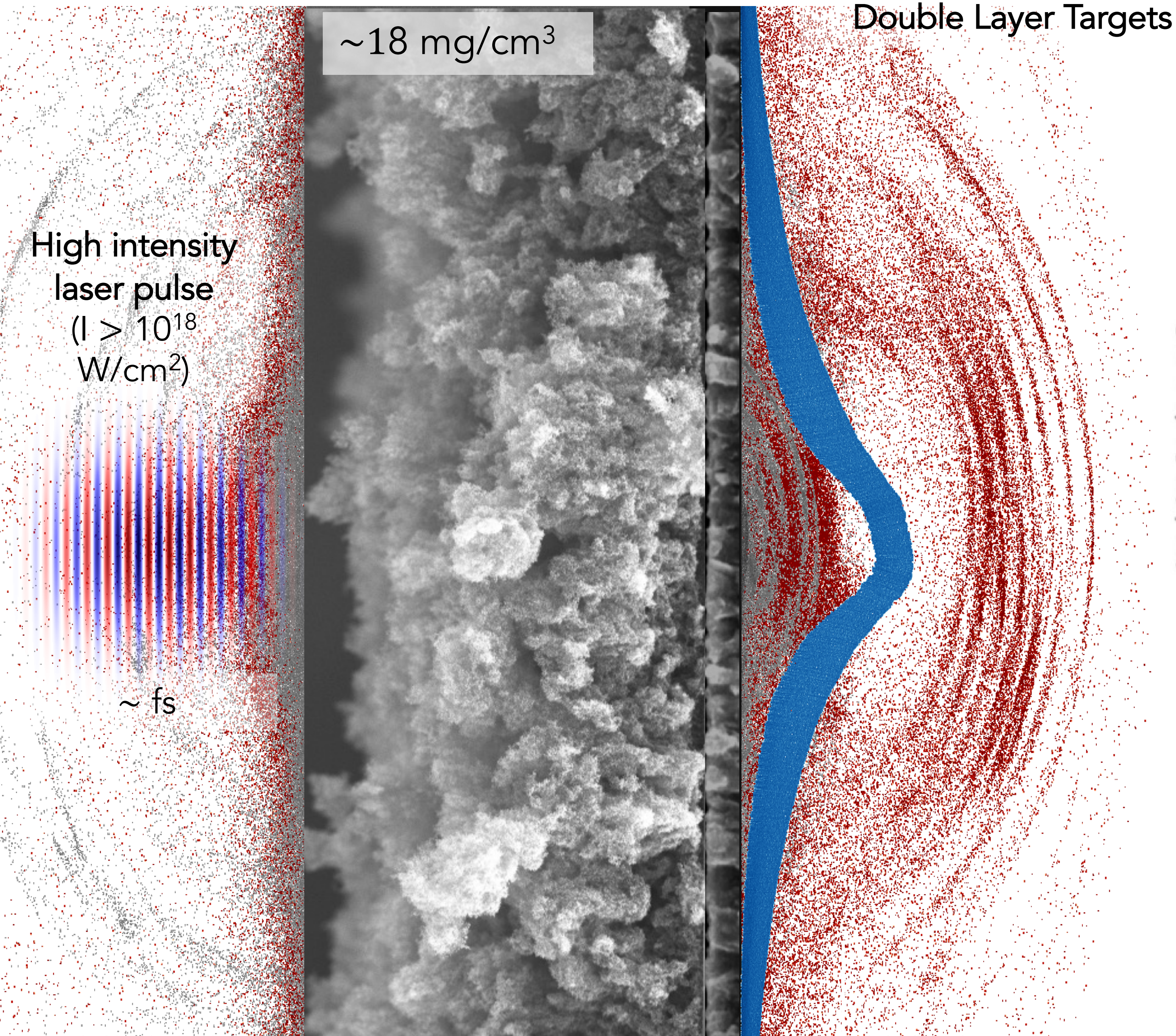
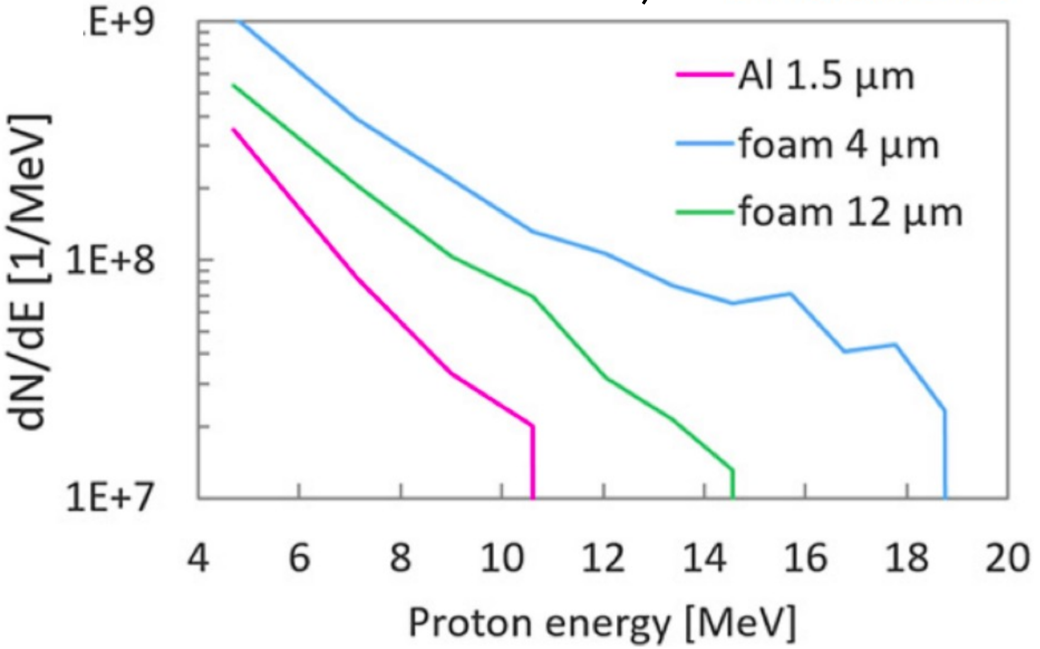
Double Layer Targets (DLTs)



Experiments @ Draco
(~2 J, ~30 fs, 150 TW,
I = 10^{18} – 10^{22}W/cm^2)

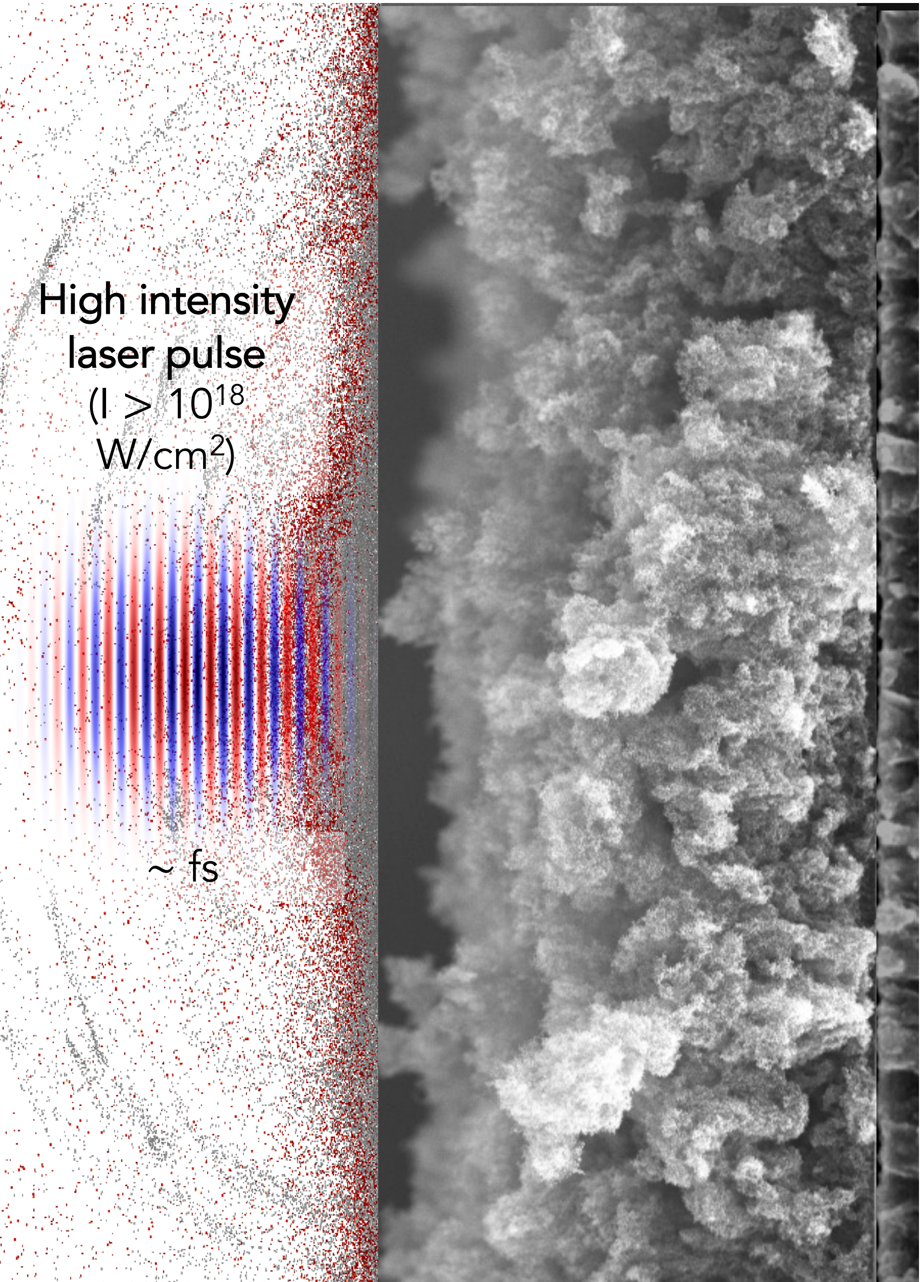
HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF



- ~ x 2 in maximum **energy**
- ~ x 4 in **number** of protons

I. Prencipe et al., New Journal of Physics, 23 093015 (2021)

C nanofoam-based targets for γ photon generation



Ritus, *J. Russ. Laser Res.* 6, 497 (1985)

Koch, *Rev Mod. Phys.* 31, 4 (1959)

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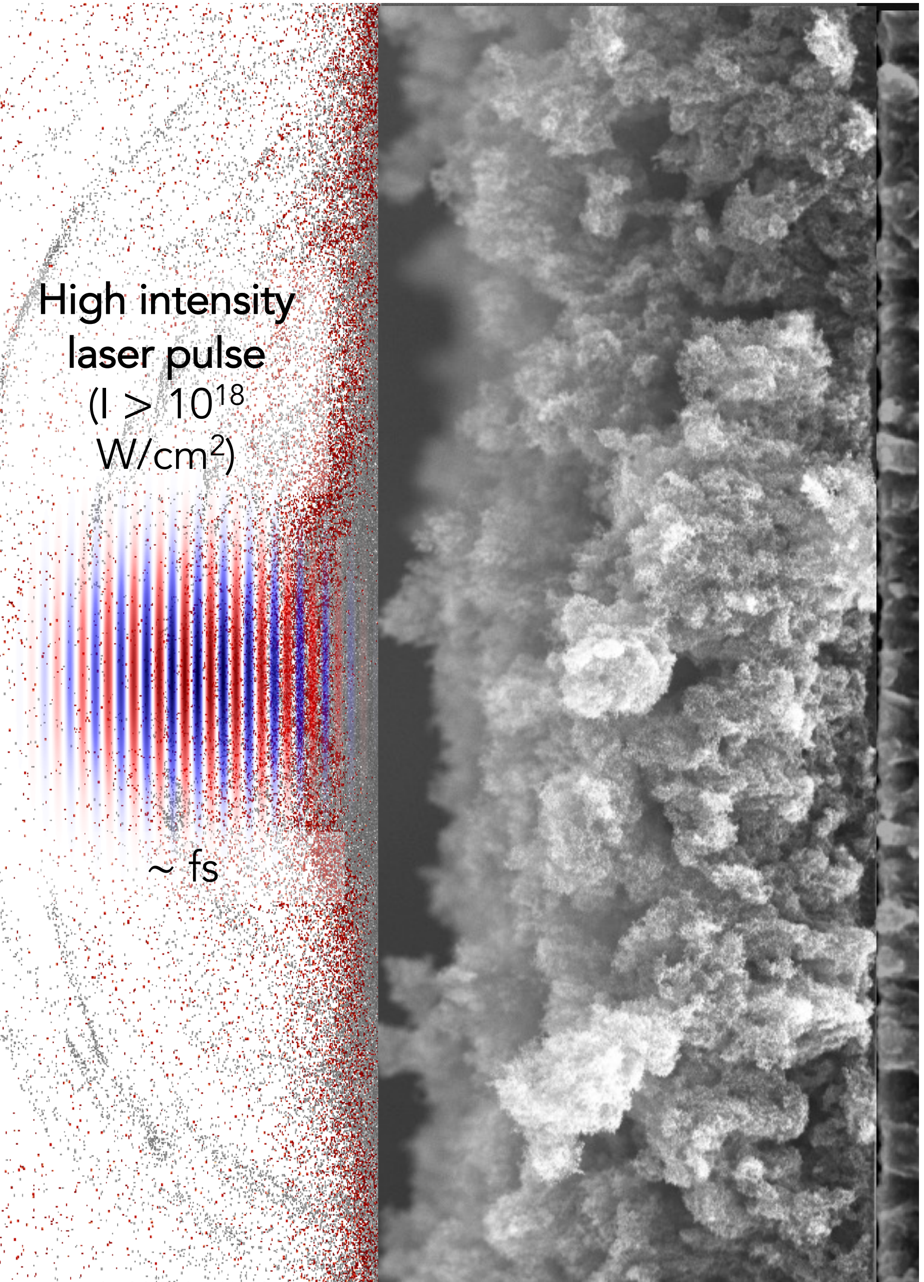

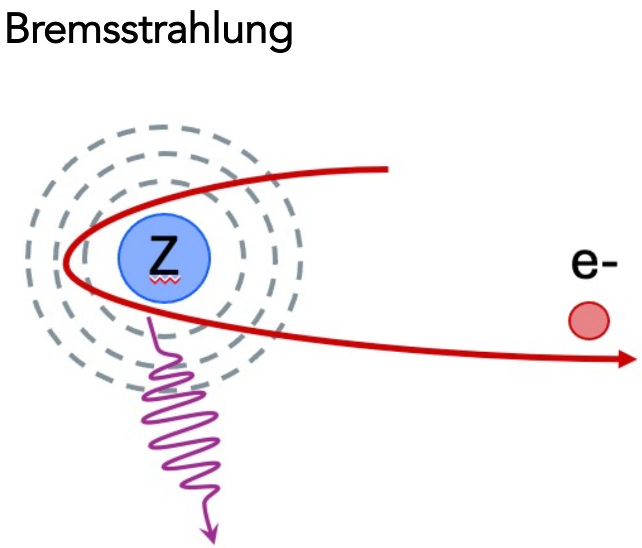

- High-Z, mm thick solid target
- ~n_c layer (C foam) can enhance hot e^-

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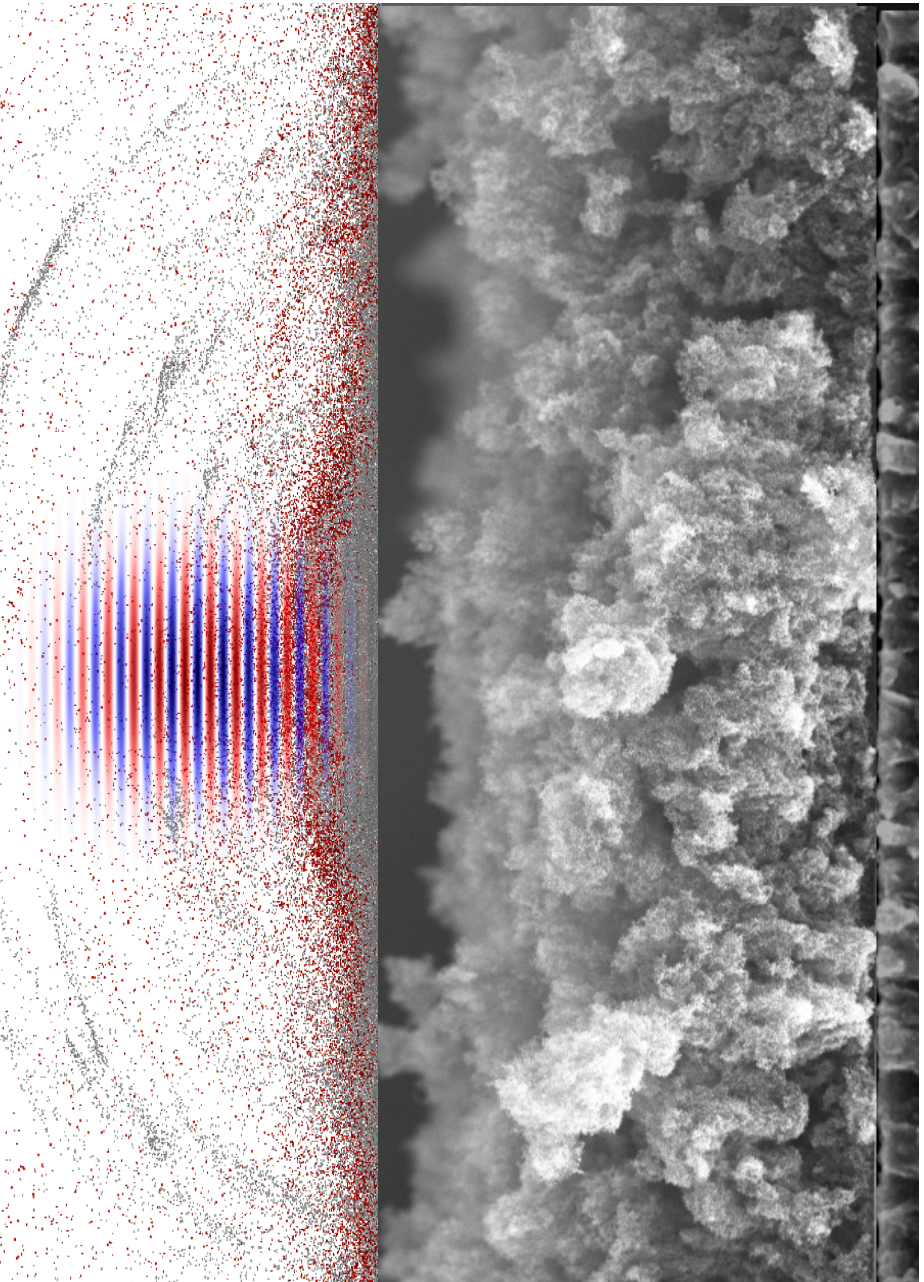
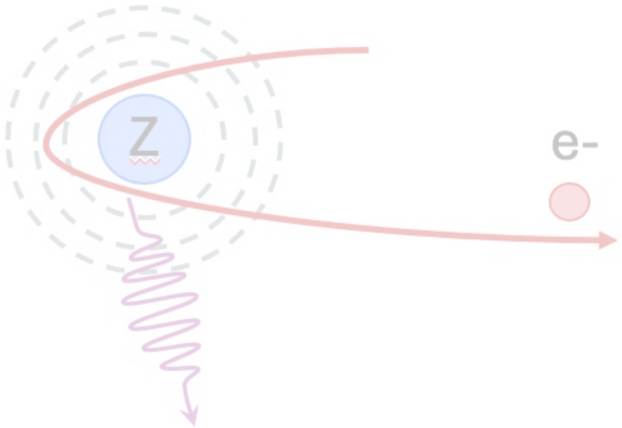


Bremsstrahlung



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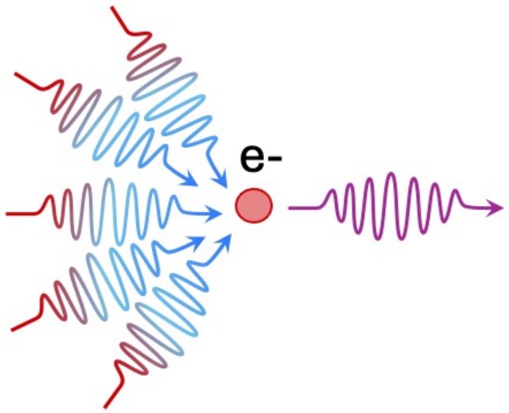
Non-linear Inverse Compton Scattering (NICS)



- Requires intense EM fields
- Requires hundreds of MeV electrons

Ritus, *J. Russ. Laser Res.* 6, 497 (1985)

Koch, *Rev Mod. Phys.* 31, 4 (1959)

C nanofoam-based targets for γ photon generation

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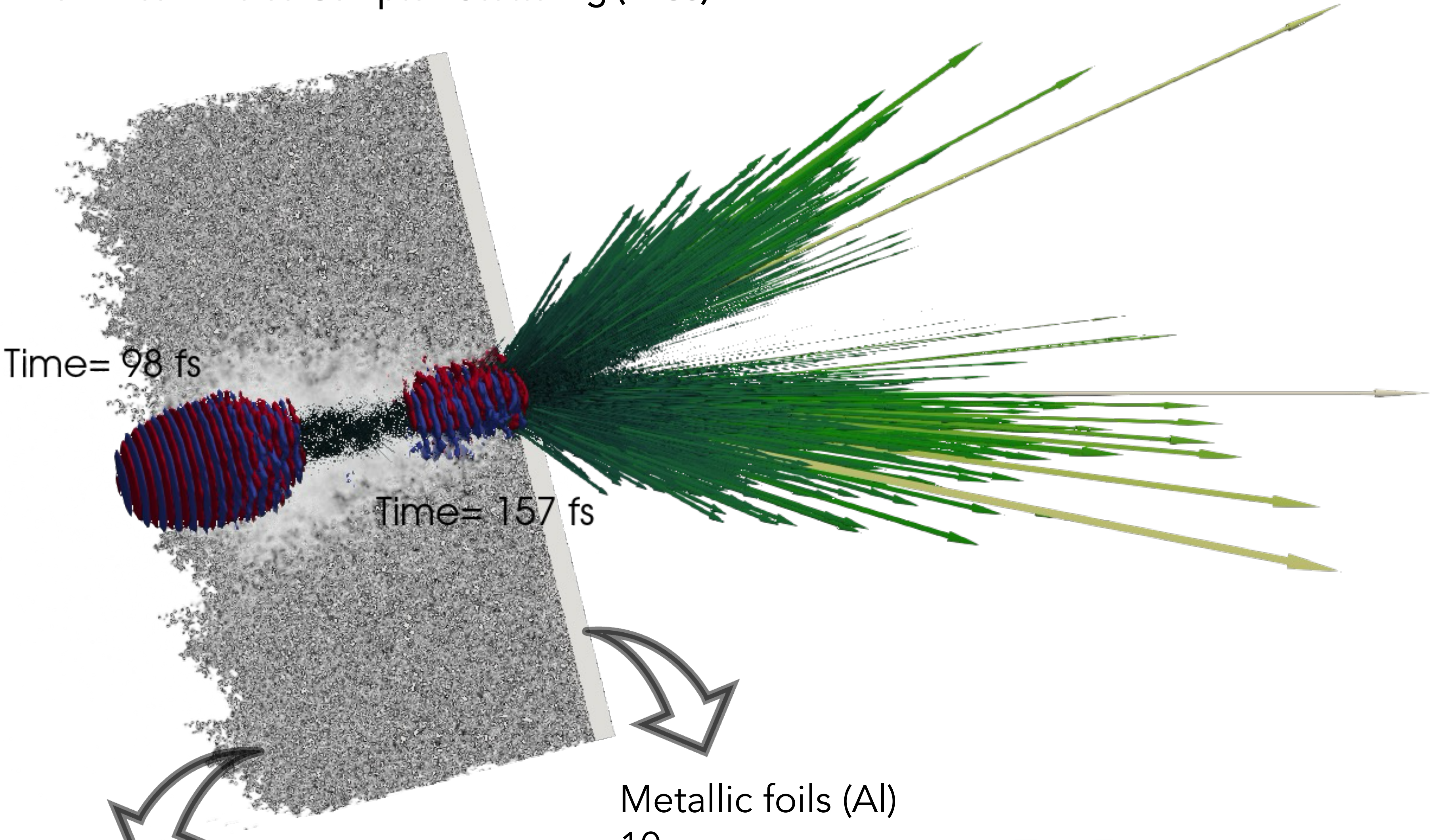


Metallic foils (Al)
10 μm

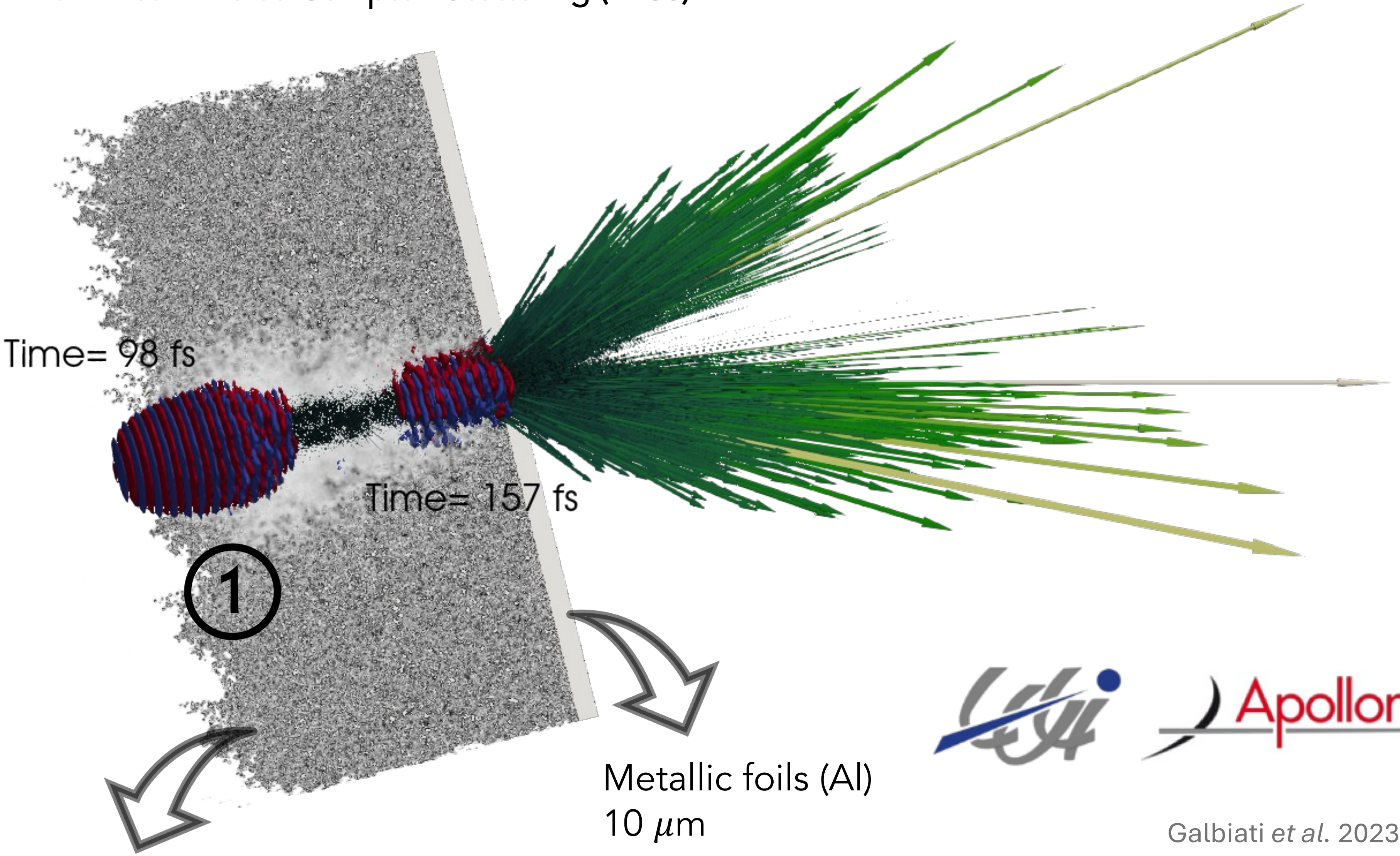
Near-critical (~8 mg/cm^3)
C foam ≥ **20 μm**

Apollon

C nanofoam-based targets for γ photon generation

Non-linear Inverse Compton Scattering (NICS)

① Hot e⁻ generation via laser-foam interaction



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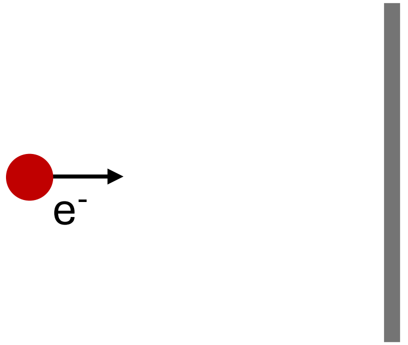

Galbiati *et al.* 2023 *Front. Phys.* 11 1117543
Formenti *et al.* 2024 *Phys. Rev. E* 109 035206
Galbiati *et al.* 2025 *preprint 10.21203/rs.3.rs-7808232/v1*

C nanofoam-based targets for γ photon generation

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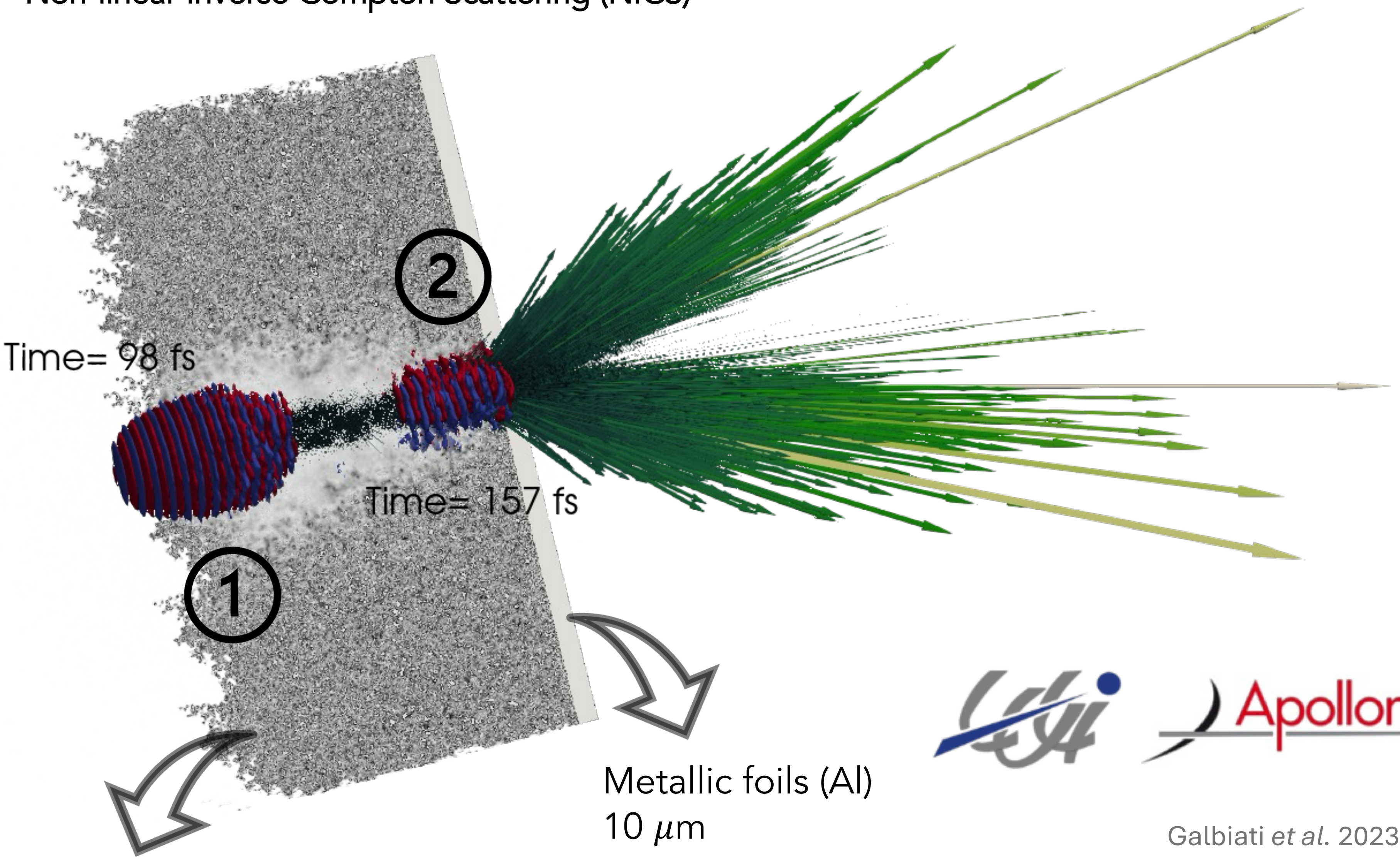

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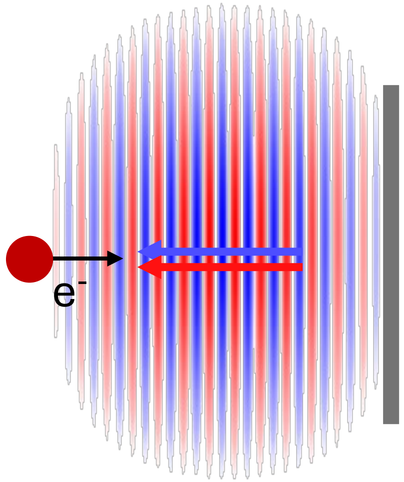
1. Hot e$^-$ generation via laser-foam interaction
2. Laser reflection on the metallic foil



Galbiati *et al.* 2023 *Front. Phys.* 11 1117543

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C nanofoam-based targets for γ photon generation

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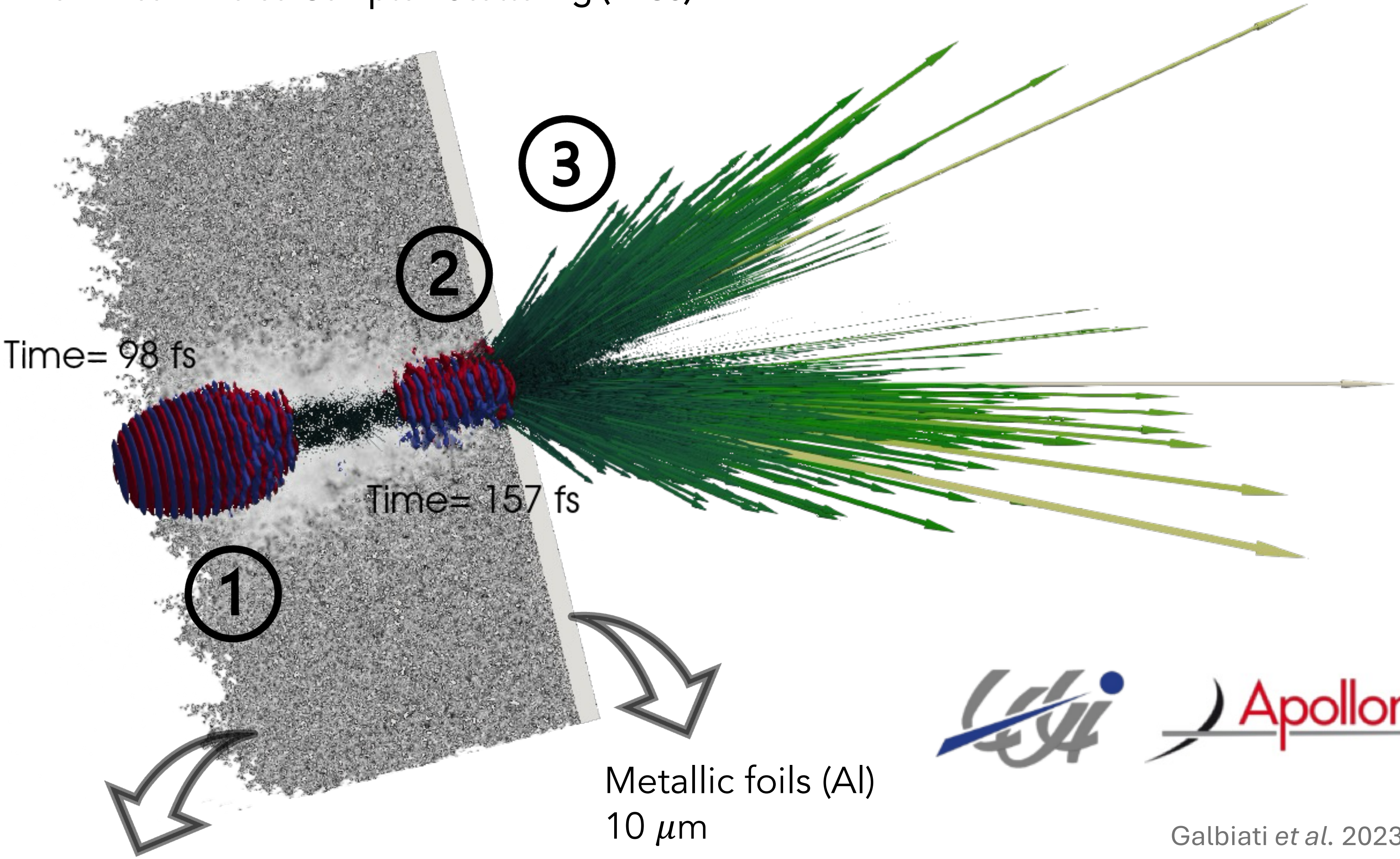
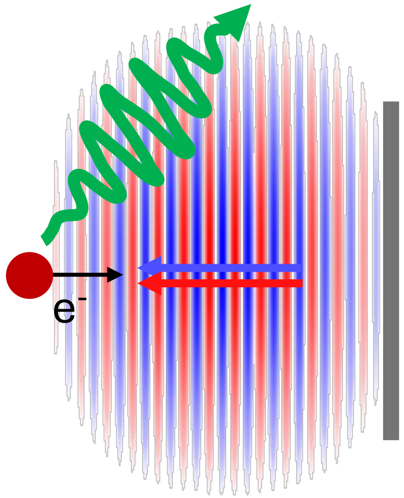


Near-critical (~8 mg/cm^3)
C foam $\geq$ **20 μm**

Metallic foils (Al)
10 μm

1. Hot e$^-$ generation via laser-foam interaction
2. Laser reflection on the metallic foil
3. Head on collision between relativistic e$^-$ and reflected laser



Apollon

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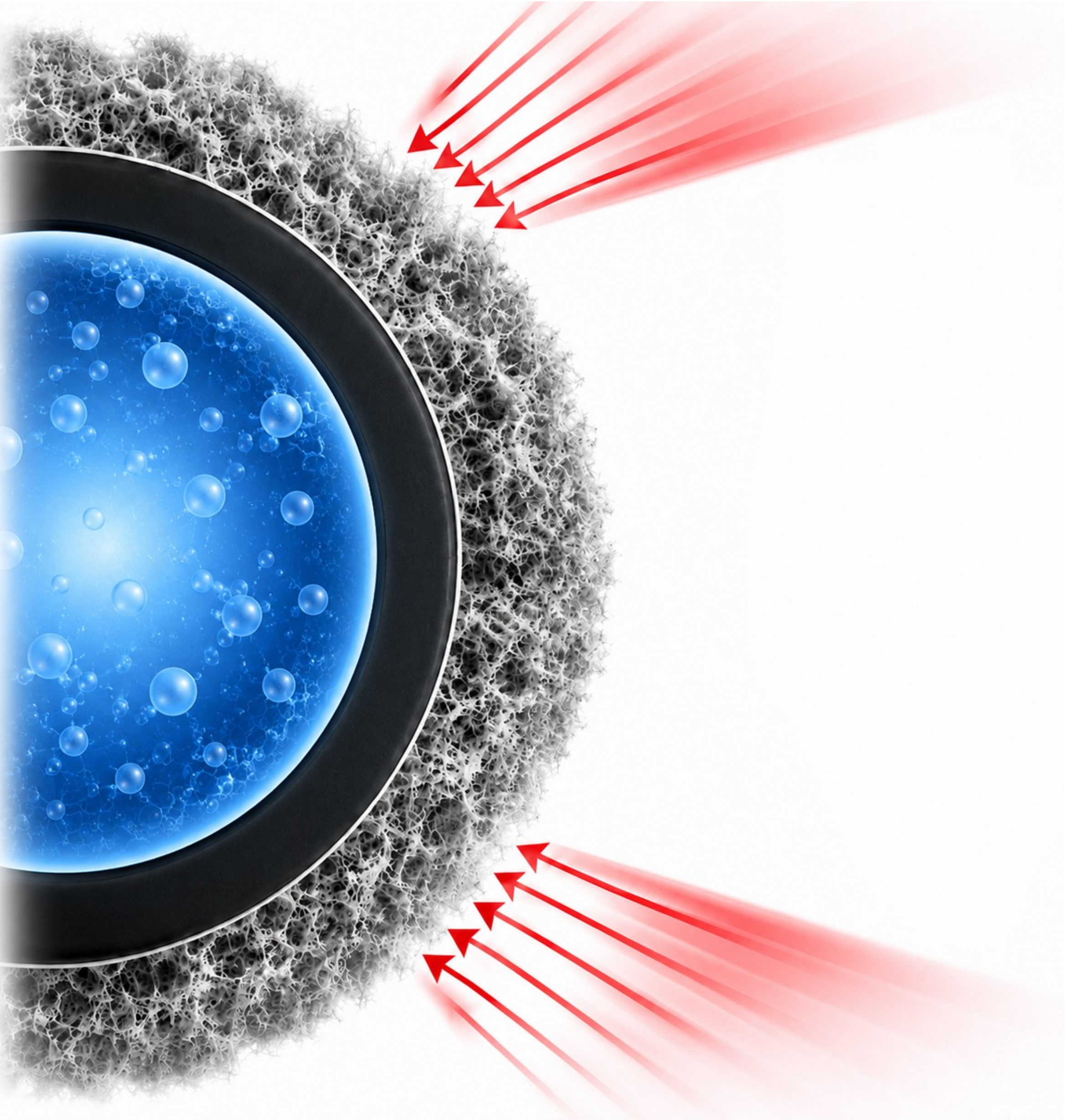
Formenti *et al.* 2024 *Phys. Rev. E* 109 035206

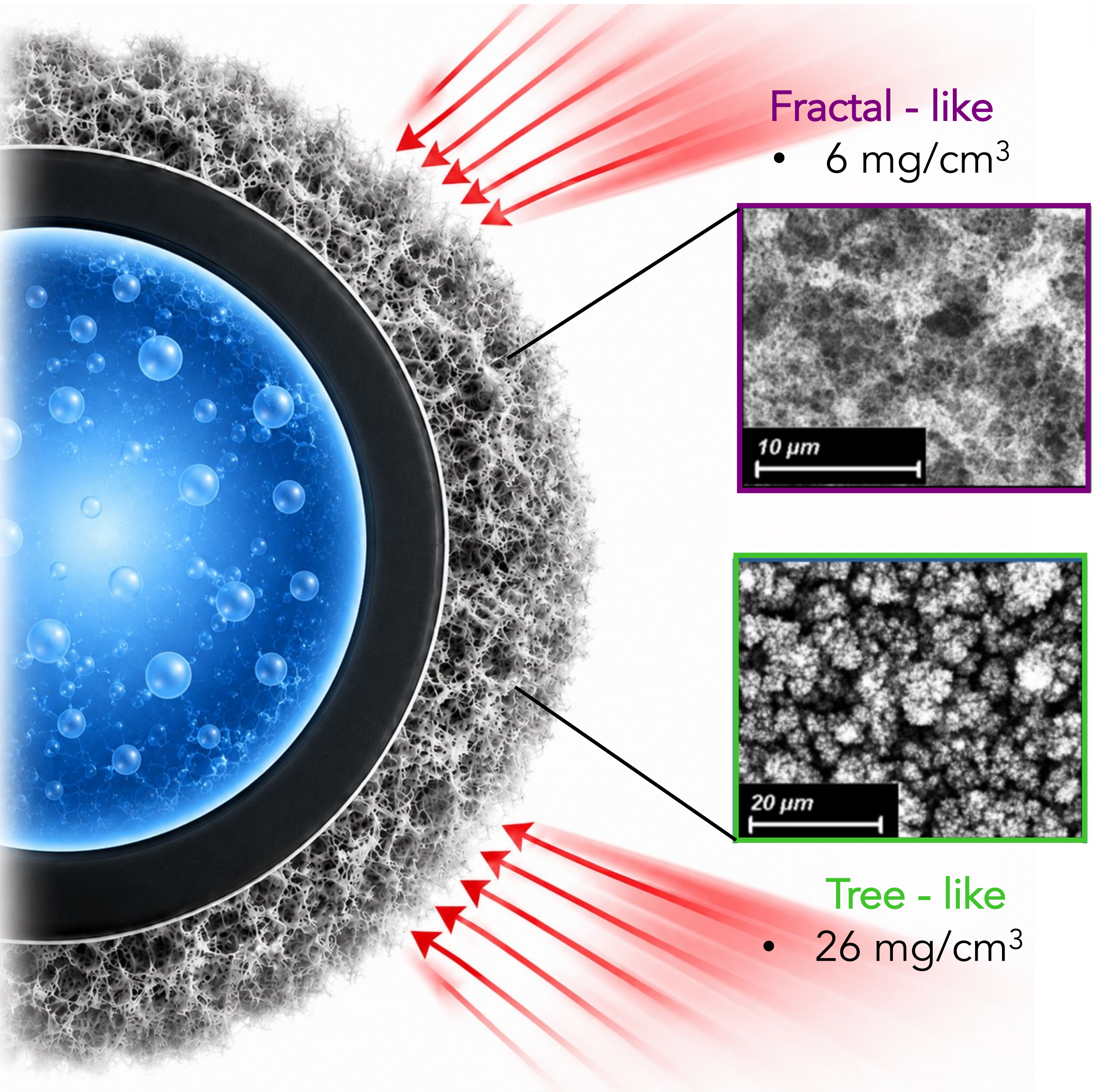
Galbiati *et al.* 2025 *preprint 10.21203/rs.3.rs-7808232/v1*

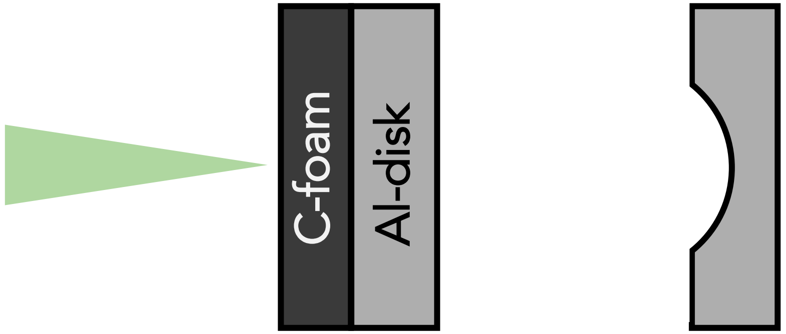
Nanofoams in laser-driven nuclear fusion



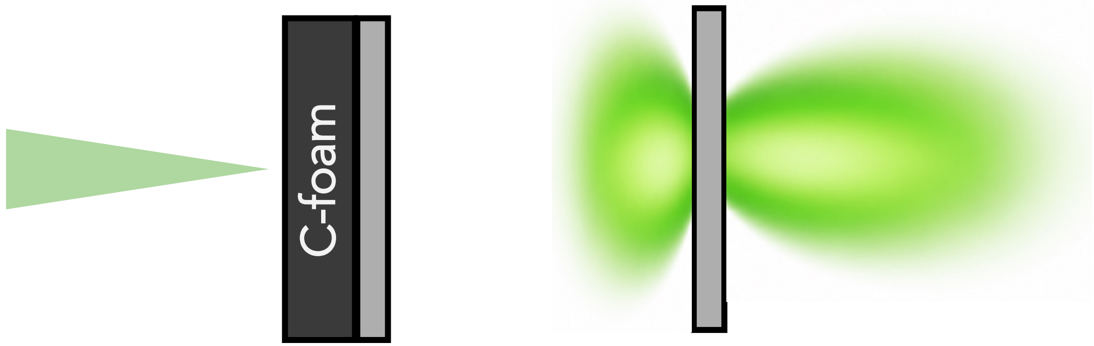
Nanofoams in laser-driven nuclear fusion

Experiments @ ABC
(~40 J, ~3 ns, I = $1.7 \cdot 10^{14}$ W/cm^2)





Compare crater volumes to have info on **relative enhancement** of **ablation efficiency**



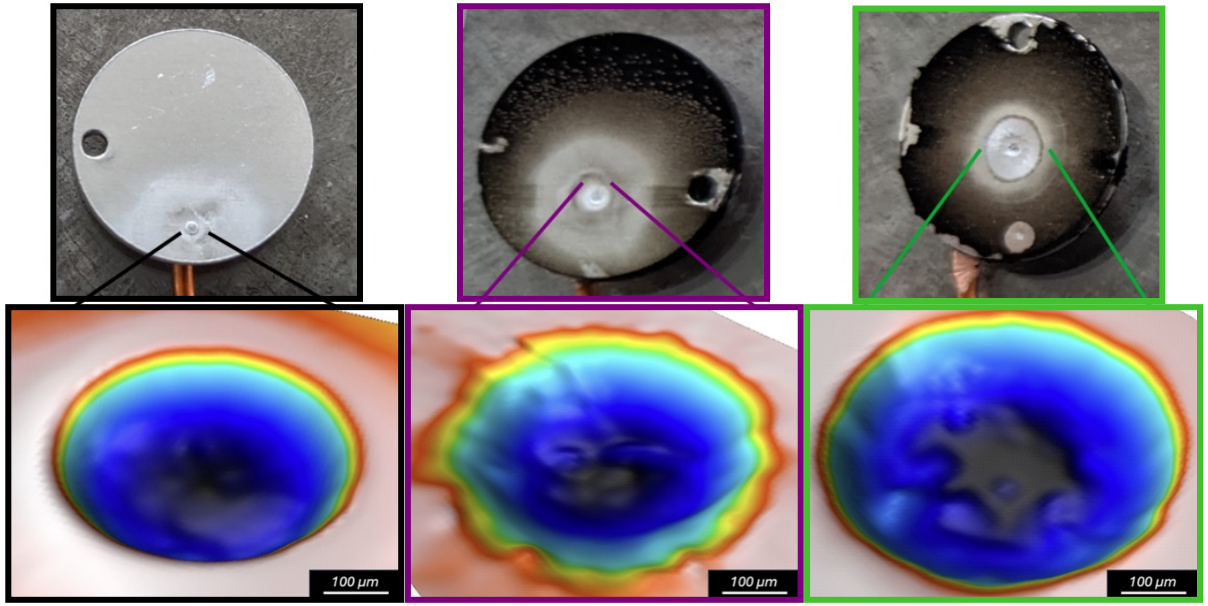
Compare plasma evolution

C nanofoams as ICF ablators

Bare Al-disk
- 1 mm

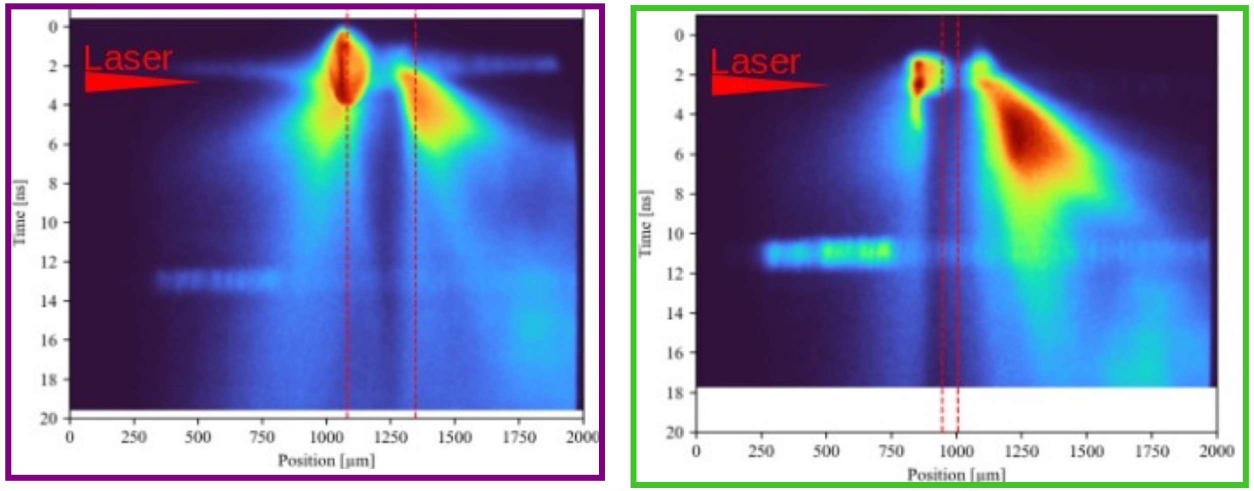
Fractal - like
- 6 mg/cm^3
- 267 μm

Tree - like
- 26 mg/cm^3
- 60 μm



V = $3.4 \cdot 10^7$ μm^3 V = $4.0 \cdot 10^7$ μm^3 V = $6.0 \cdot 10^7$ μm^3

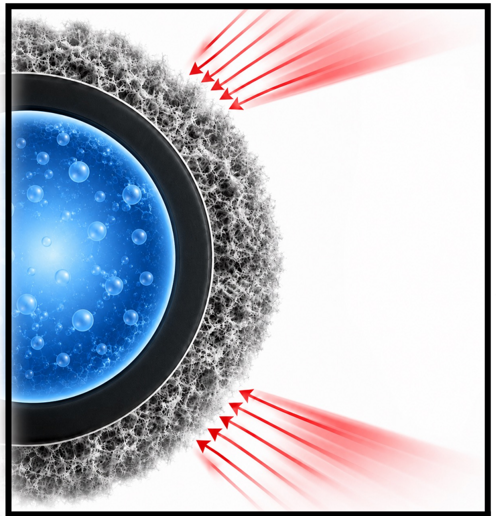
Fractal - like 156 μg/cm^2 Tree - like



Tree-like foam **enhances** ablation loading efficiency

M. Cipriani et al., Matter and Radiation at Extremes, 11, 047402 (2026)

Interaction of high power-lasers with PLD targets

Proton acceleration	γ photons generation	Inertial Confinement Fusion (ICF)	p-^{11}B
			
30-180 fs / 10^{18} – 10^{20} W/cm^2	23 fs / 10^{21} W/cm^2	3 ns / 10^{14} W/cm^2	800 fs / 10^{19} W/cm^2

Tailoring C nanofoam properties

Sequential deposition of different materials

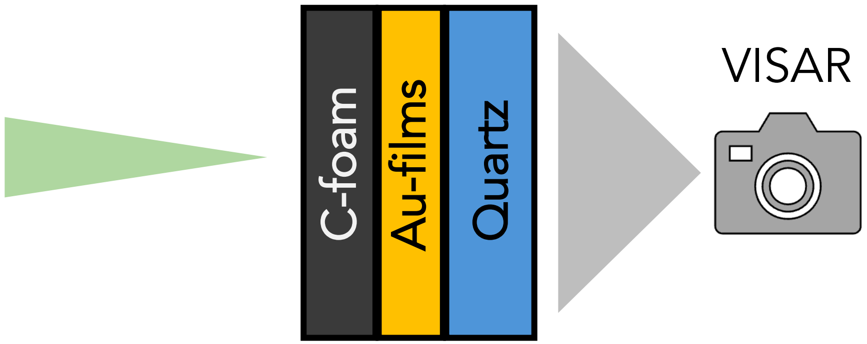
Co-deposition of B and plastics

A. Maffini et al., Plasma Physics and Controlled Fusion, 68, 035007 (2026)

Multi-layered targets for ICF experiments

Experiments @ LULI-2000
(up to 1 kJ, 2 x ns beams)

Investigate the **performance** of different **ablator** materials



- Quartz = reference target material
- Au films = X-ray shield/avoids pre-heating

Multi-layered targets for ICF experiments

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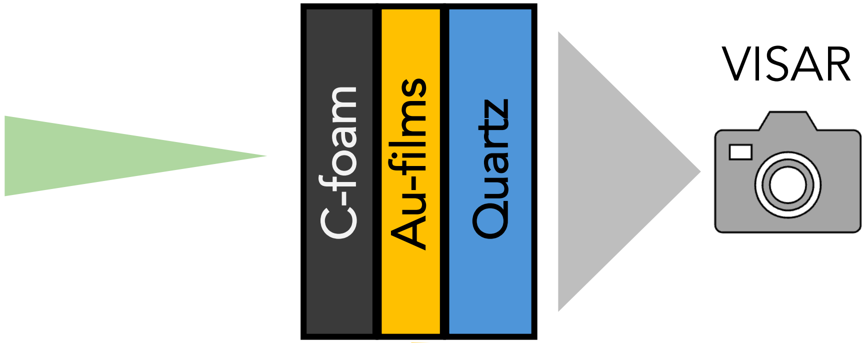
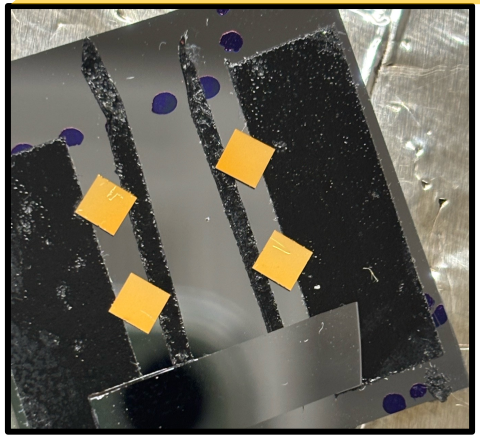


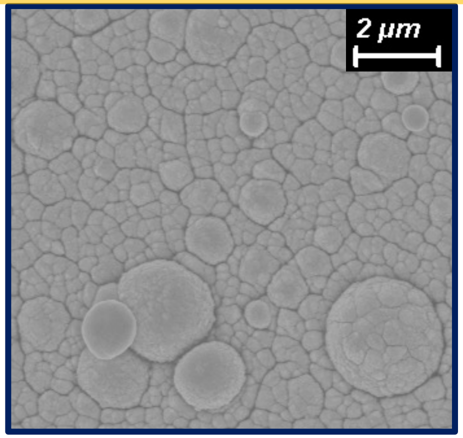
Glued stacked layers

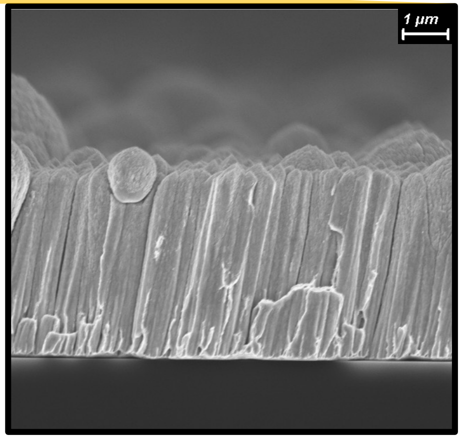
- Poor adhesion
- Non uniformities
- Distortions in the shock

Pulsed Laser Deposition

- Sequential layer deposition
- Improved adhesion and smooth interfaces







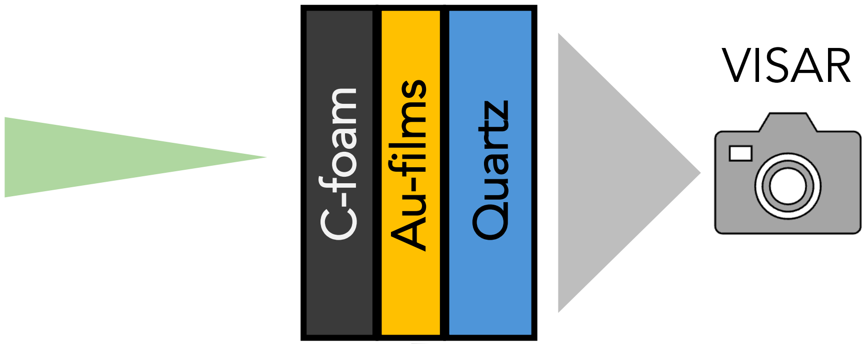
Compact 5 µm. micro-columnar morphology

Successfully prevented pre-heating

Multi-layered targets for ICF experiments

Experiments @ LULI-2000
(up to 1 kJ, 2 x ns beams)

Investigate the **performance** of different **ablator** materials



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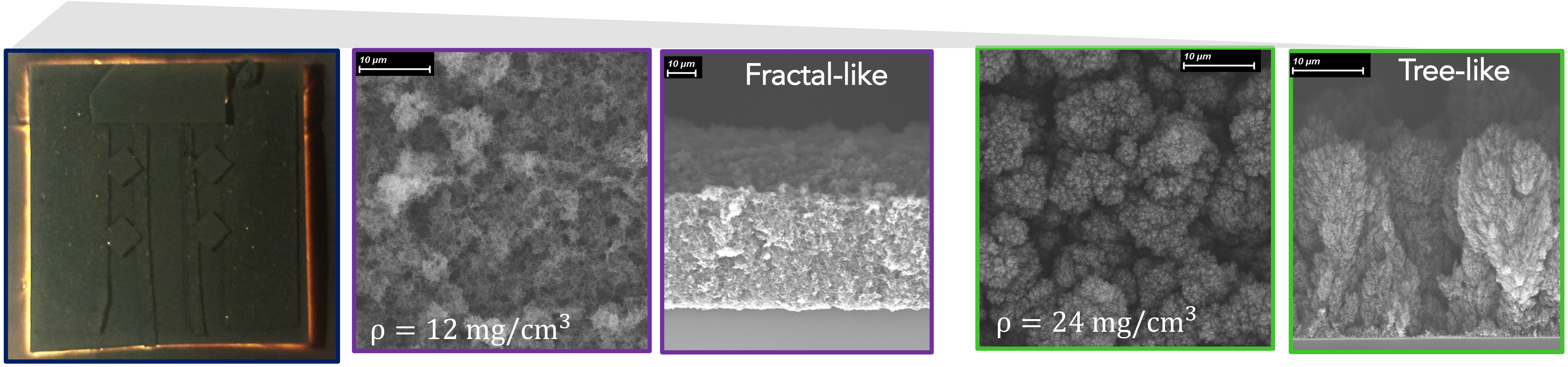


Data analysis in progress …

Interaction of high power-lasers with PLD targets

Proton acceleration

30-180 fs | $10^{18} - 10^{20}$ W/cm^2

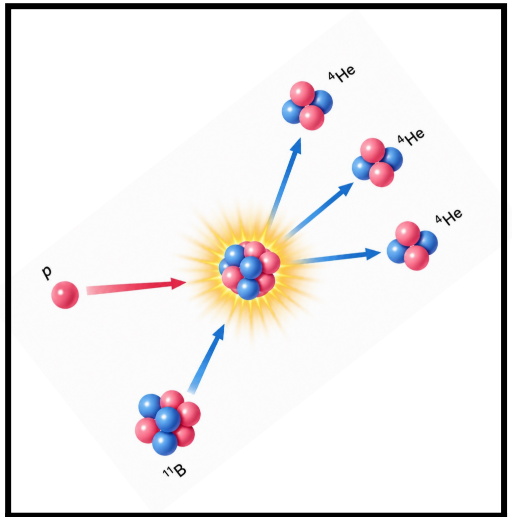
γ photons generation

23 fs | 10^{21} W/cm^2

Inertial Confinement Fusion (ICF)

3 ns | 10^{14} W/cm^2

p-^{11}B



800 fs | 10^{19} W/cm^2

Tailoring C nanofoam properties

Sequential deposition of different materials

Co-deposition of B and plastics

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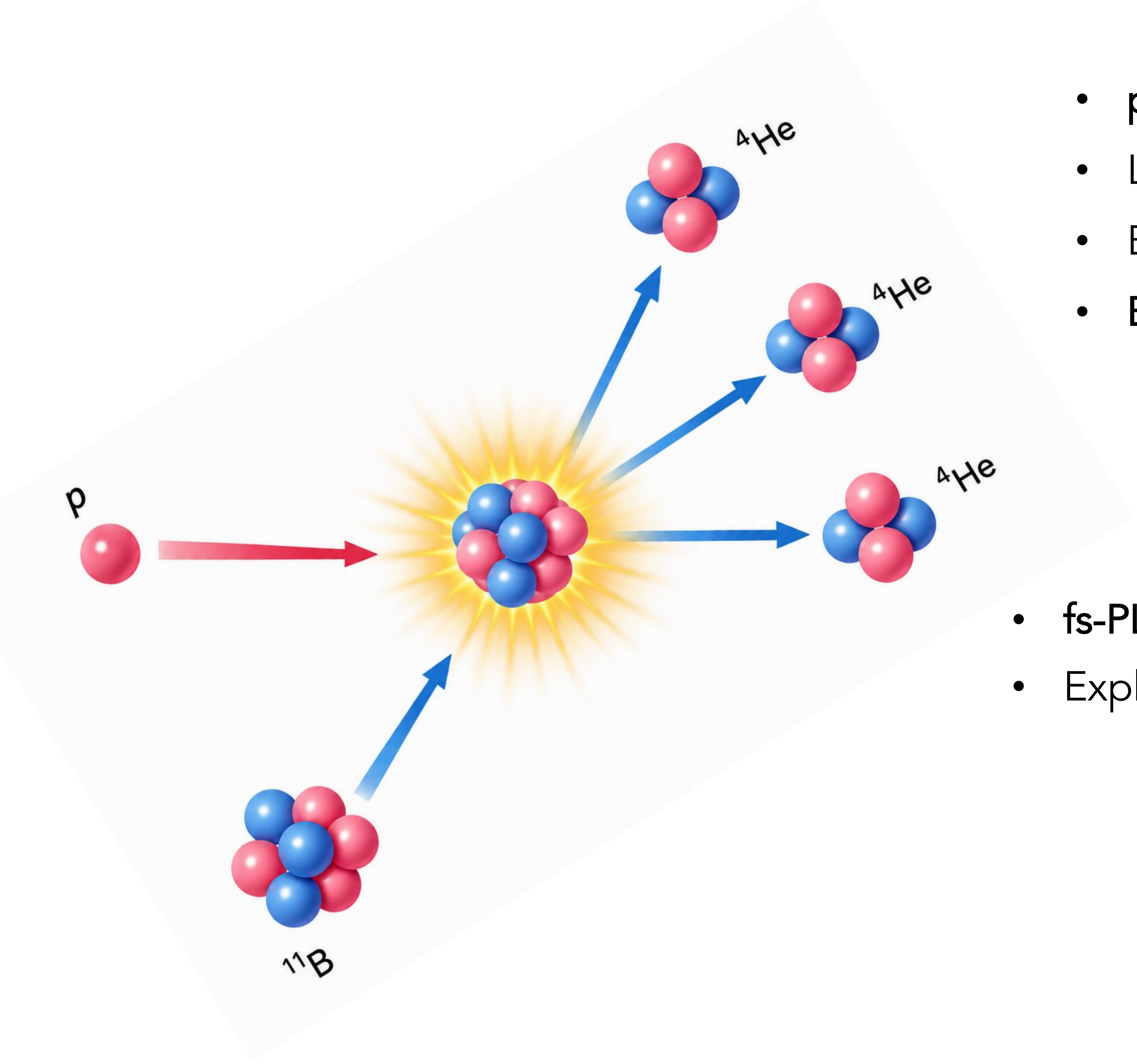
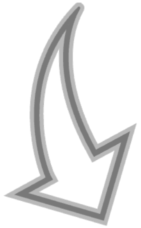
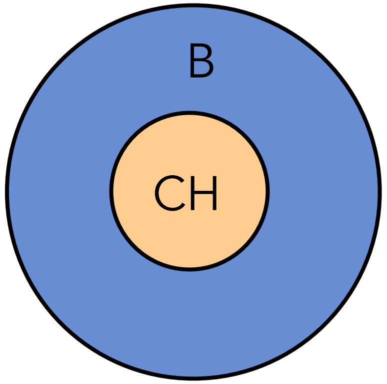
Plastic nanofoams for p-^{11}B fusion



- **p-^{11}B** reaction has a **low cross-section**
- Laser-driven **in-target** schemes
- B-H compounds are mostly unstable or toxic
- **BN** most exploited target but **H** is only an **impurity**



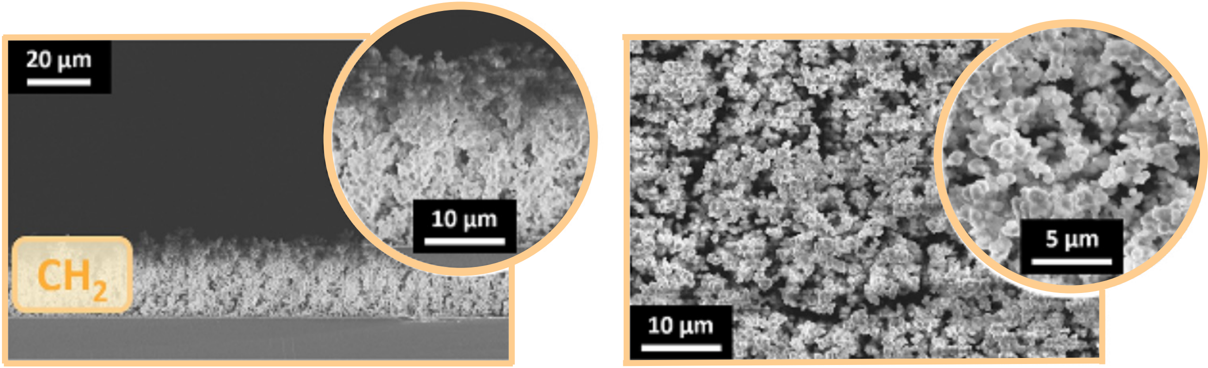
- **fs-PLD** allows **plastic** ablation through non-linear processes
- Exploit sequential or **simultaneous** depositions of **B** and **CH**



Plastic nanofoams for p-^{11}B fusion

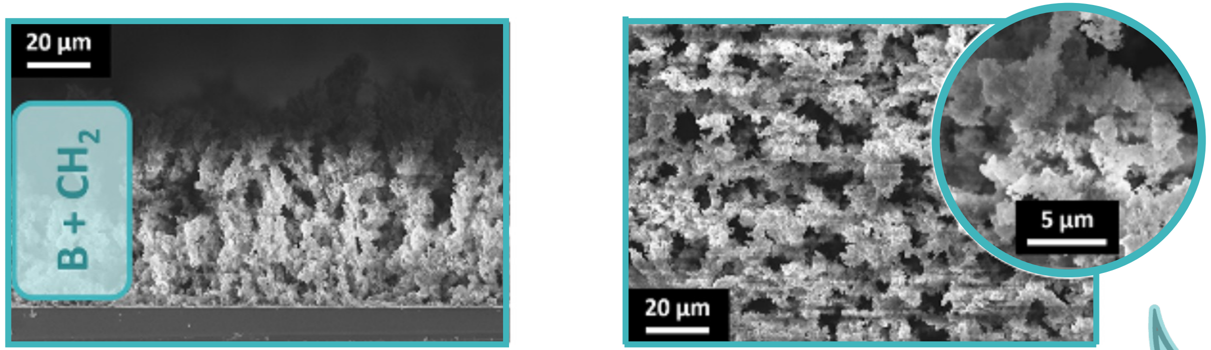
Plastic foam on Boron nitride

- 140 mg/cm^3
- 20 μm



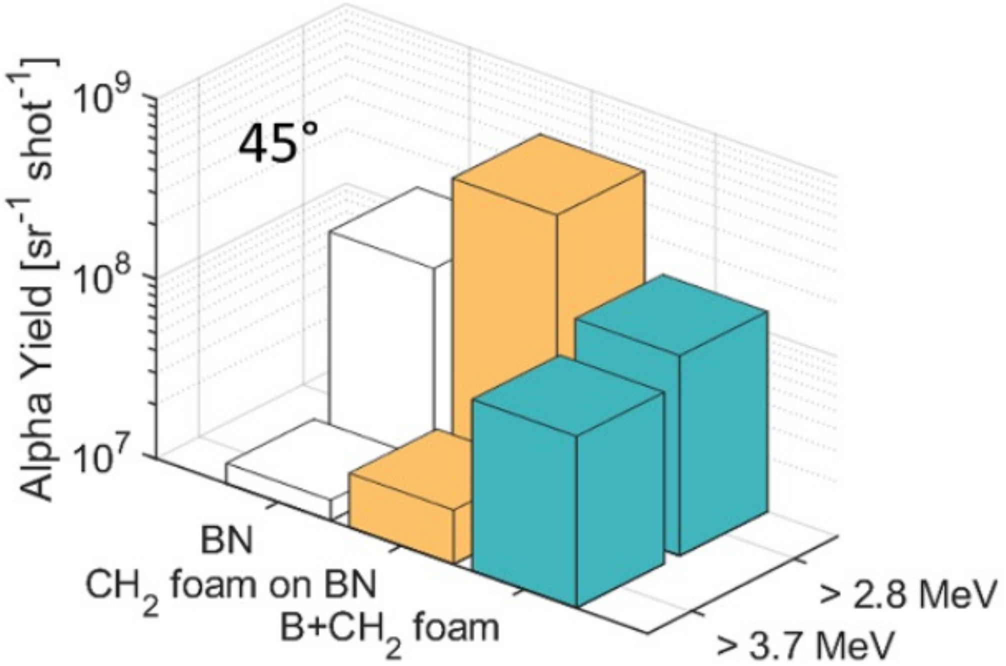
B + plastic foam on polypropylene

- 40 – 80 mg/cm^3
- 60 - 100 μm



Experiments @ Taranis
(~8 J, ~800 fs, ~10^{19} W/cm^2)

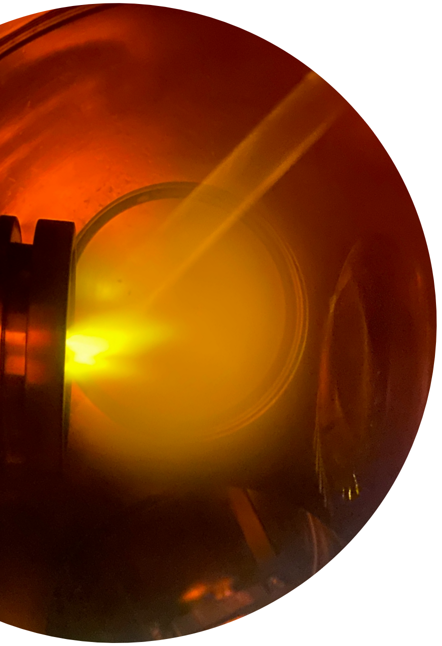
QUEEN'S UNIVERSITY BELFAST



In-foam p-^{11}B fusion reaction
α yield **enhancement**

D. P. Molloy *et al.*, Physical Review Research, 7, 013230 (2025)

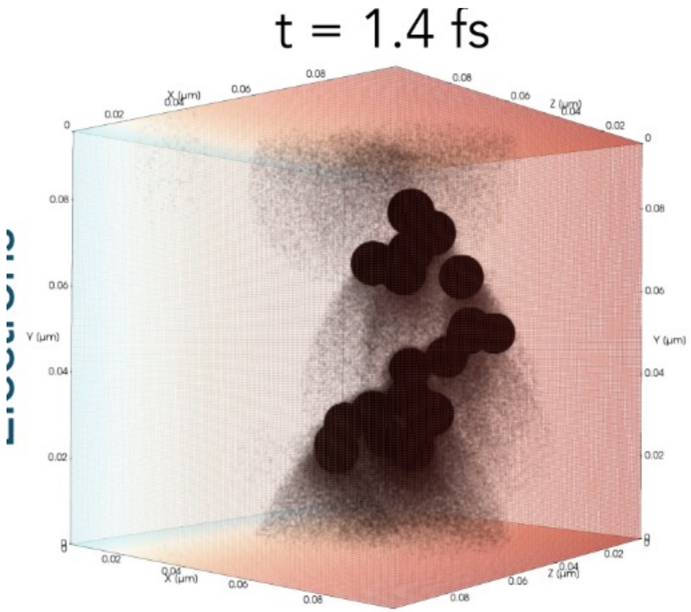
Conclusions



- **PLD** is a **versatile technique** for the fabrication of nanostructured films, from compact to foams
- Fine **control over film properties** in terms of morphology, density, composition thickness …
- Tested in **different experiments** showing promising results
  - Proton acceleration
  - γ photon generation
  - Ablation loading efficiency
  - In-foam p-^{11}B fusion

- Simulations to investigate foam aggregation process and interaction with high-power lasers

Kevin Ambrogioni's talk "kinetic study of nanofoam homogenization under intense laser irradiation" @ 14.00



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Collaborations

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Projects

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Thank you for your attention!

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