POLITECNICO MILANO 1863

IWPROBONO 2026

International Workshop on PROton BOron Nuclear fusion from energy production to medical applicatiOns

Pulsed Laser Deposition as a versatile technique for tailored boron-based targets in p-^{11}B fusion

Davide Orecchia, M. Iaccarino, M. S. G. De Magistris, F. Mirani, K. Ambrogioni, D. Vavassori, V. Russo, D. Dellasega, A. Maffini and M. Passoni

NanoLab

CA 21128 PROBONO

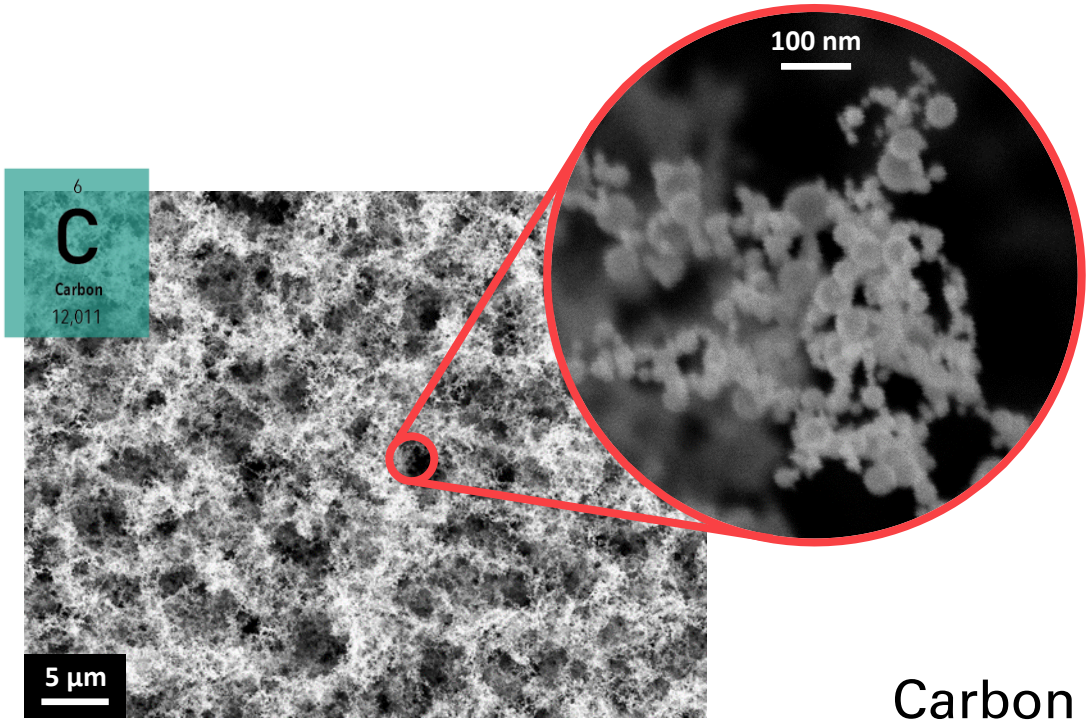
Istanbul – **8** oct **2026**

Foams in laser-matter interaction

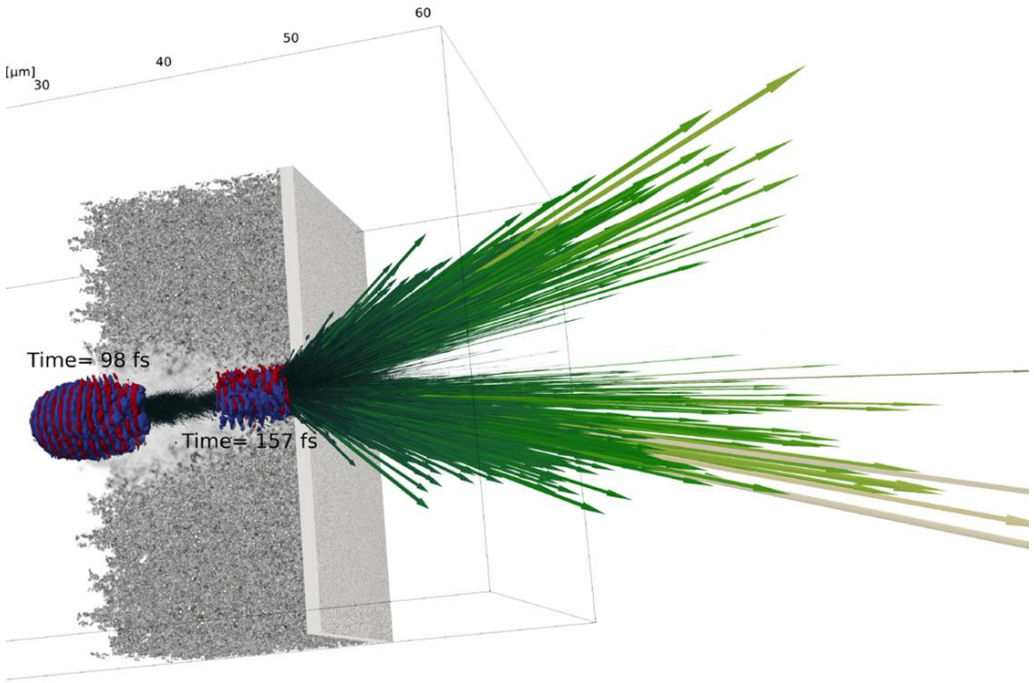
Disordered web-like structure

Density as low as a **few mg/cm^3**

Nanostructured



Efficient laser energy absorption + **Robust** against uncontrolled variables



Carbon **nanofoam** ▷ **Double Layer Target**

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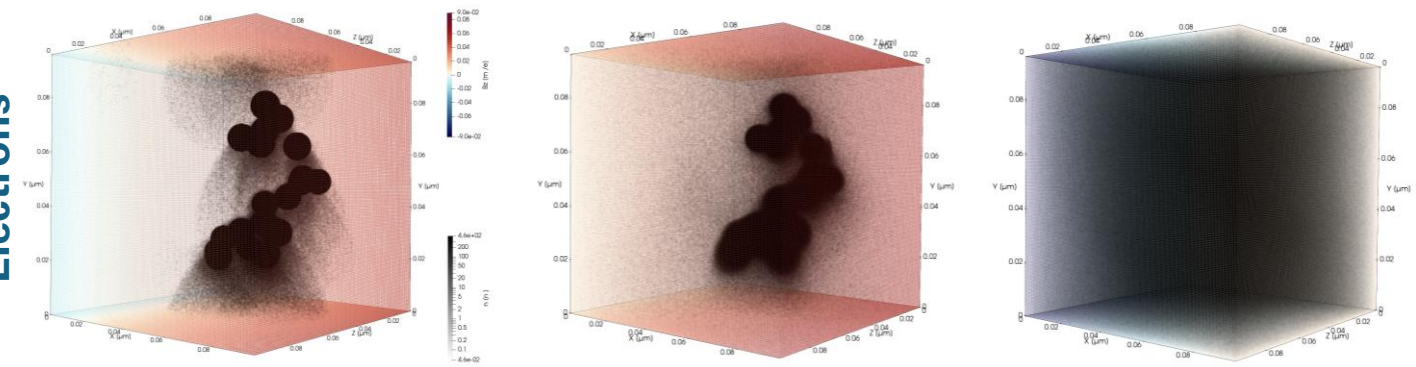
Introduction

Why nanofoams? Nanostructure effects

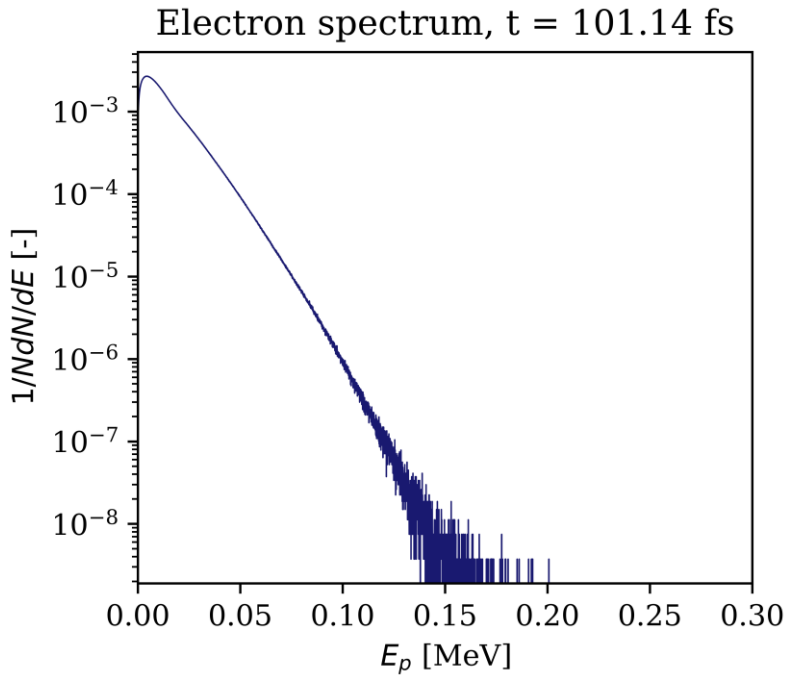
Nanofoam cluster **homogenization**

1.4 fs | 12 fs | 102 fs

Electrons



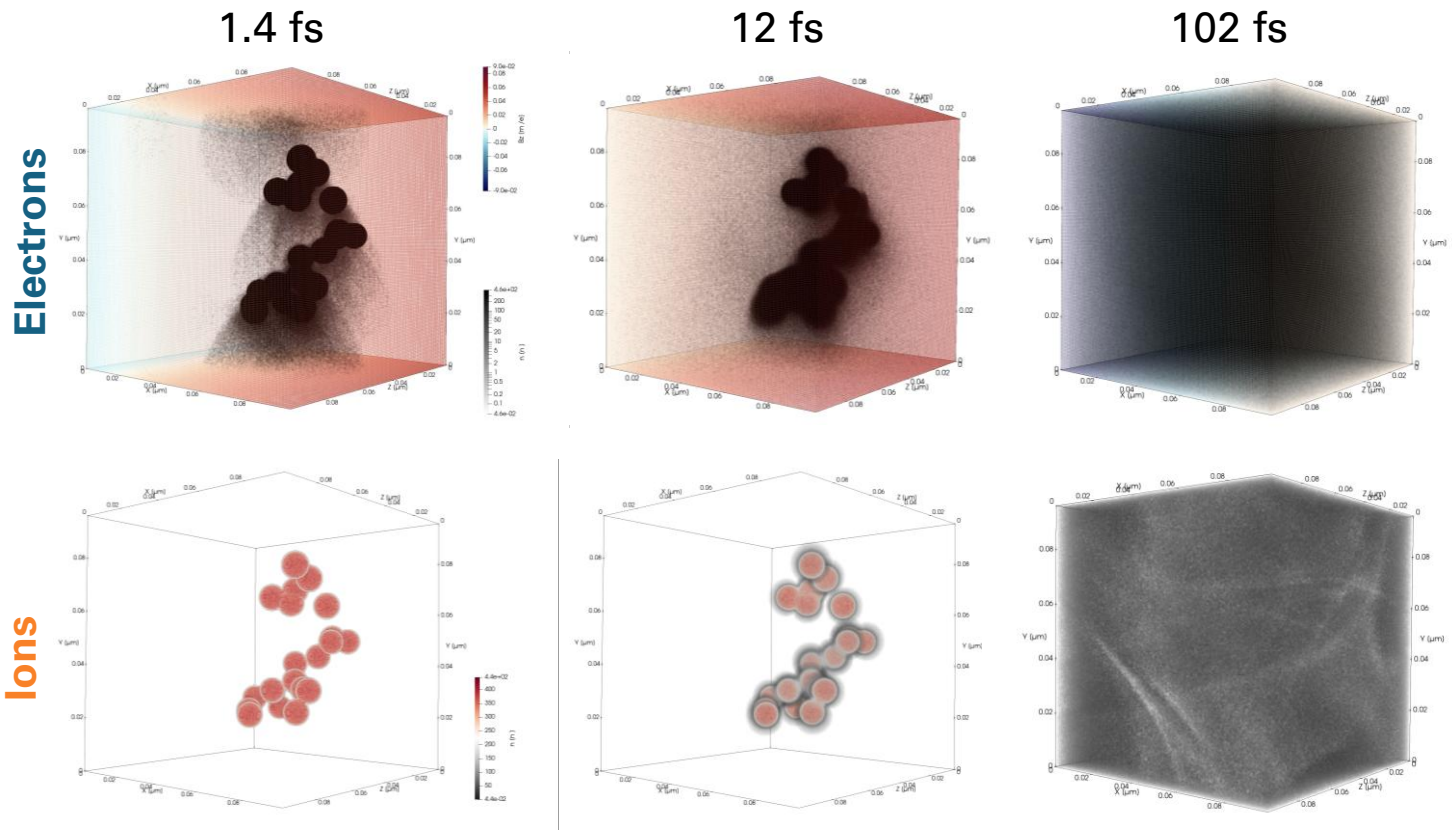
Maxwellian electron spectrum



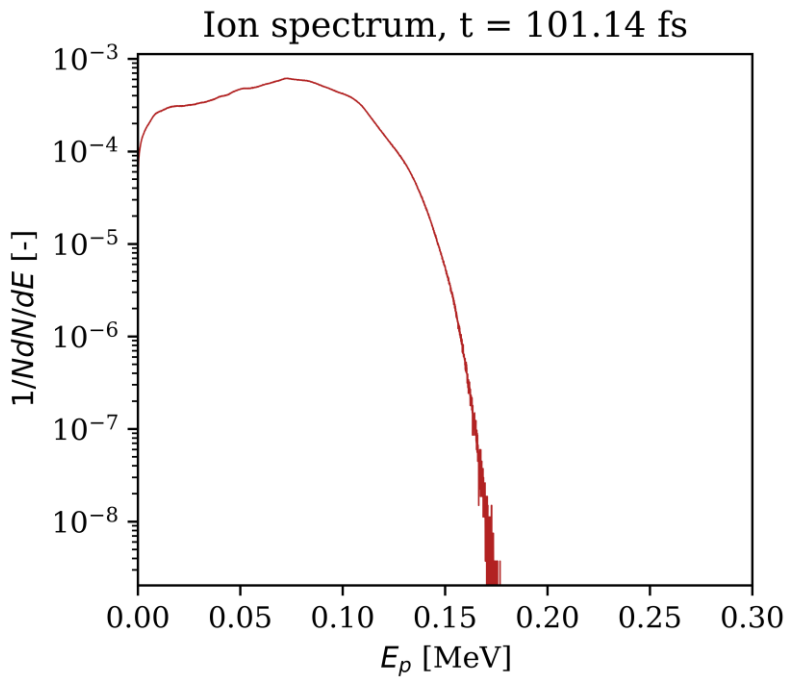
Images courtesy of K. Ambrogioni

Why nanofoams? Nanostructure effects

Nanofoam cluster **homogenization**



Non-Maxwellian ions, peaked at high energy



Images courtesy of K. Ambrogioni

Coulomb explosion

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Introduction

Material synthesis: nanofoams and more

- **Flexibility**
- Nanostructure & material properties **control**

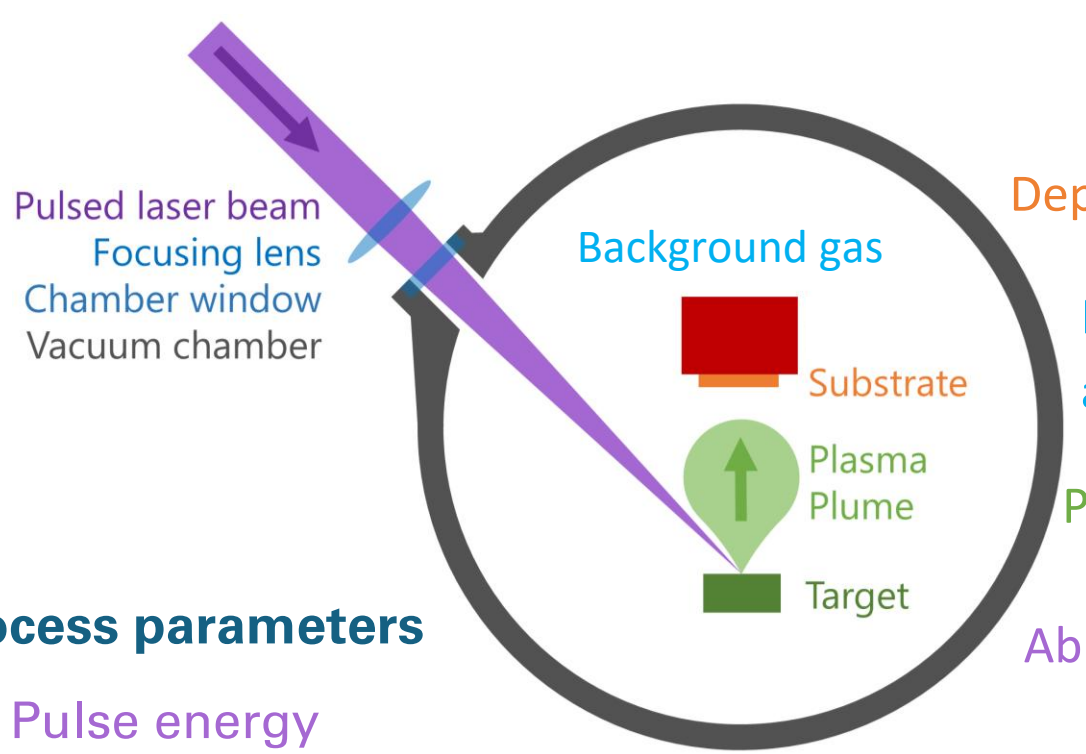
Chemical techniques

Top-down

Bottom-up

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Pulsed Laser Deposition (PLD)



Process parameters

- Pulse energy
- Target-substrate distance
- Background gas pressure
- Substrate

Laser **pulse duration**

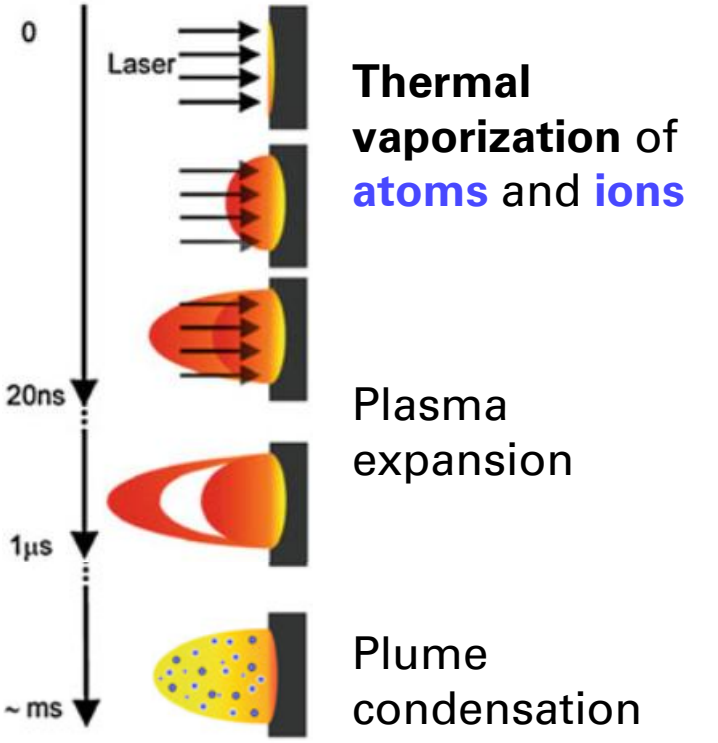
- ns-PLD ✓
- fs-PLD

Pulsed Laser Deposition

ns-PLD and fs-PLD techniques

Different **ablation regimes**

ns-PLD

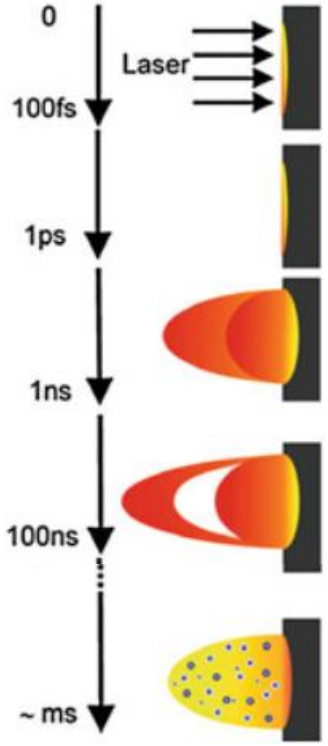


Thermal vaporization of **atoms** and **ions**

Plasma expansion

Plume condensation

fs-PLD



Electronic ablation of **nanoparticles**

Plasma expansion

Plume condensation

ns-PLD

- **Well-established**
- Better **thickness uniformity**
- Atom-by-atom deposition
- **Gas-mediated** nanoparticle synthesis

fs-PLD

- **Direct** nanoparticle synthesis
- High ablation efficiency
- Technically **challenging**
- Great flexibility in **material choice**

Adapted from Harilal S.S. et al., in "Laser-induced breakdown spectroscopy", ch. 6, 2014

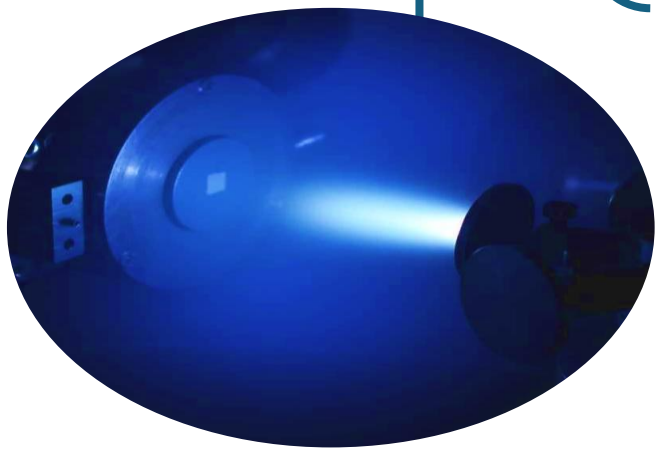
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Pulsed Laser Deposition

PLD laser parameters

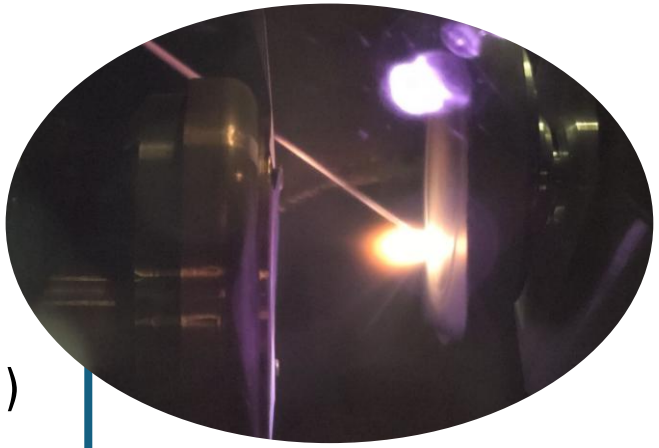
ns-PLD

- Nd:YAG (SH @ **532 nm**)
- **5 – 7 ns** pulse duration
- 100 – 600 mJ per pulse
- **100 – 600 mJ/cm²**
- 10 Hz



fs-PLD

- Ti:Sapphire (**800 nm**)
- **~80 fs** pulse duration
- 1 – 4 mJ per pulse
- **100 – 600 mJ/cm²**
- 1 kHz



Coherent **Astrella**



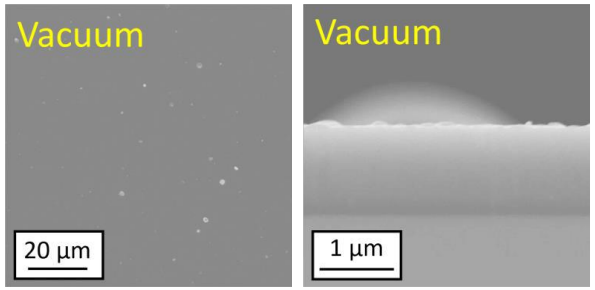
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Pulsed Laser Deposition

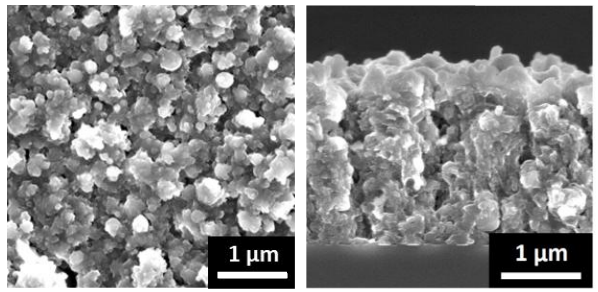
Boron thin films and nanofoams

Compact films

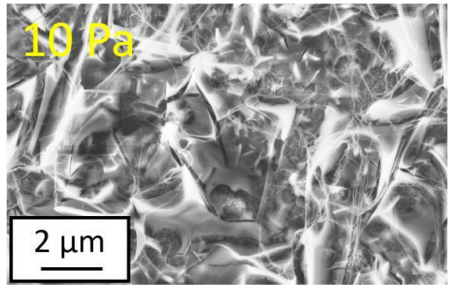
ns-PLD

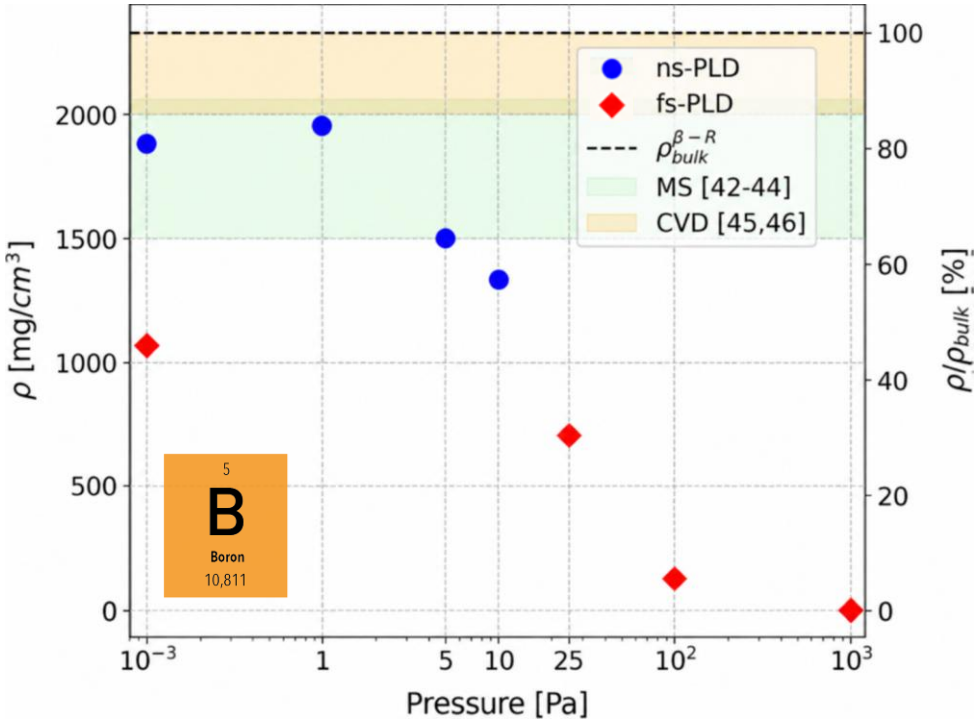


fs-PLD



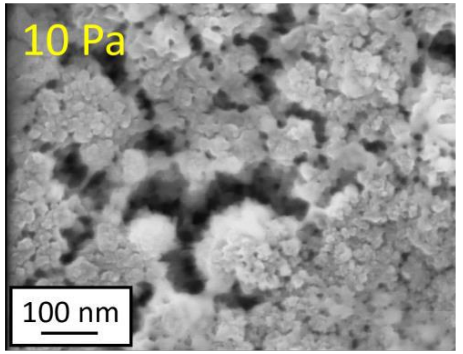
Oxidation and degradation



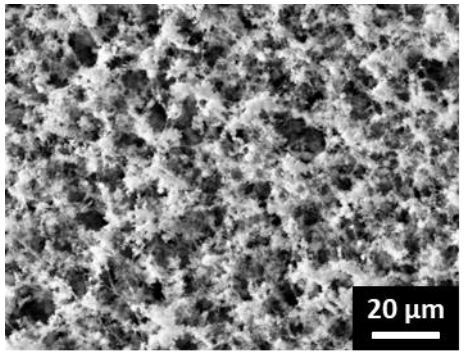


Low density nanofoams

ns-PLD



fs-PLD



fs-PLD

ns-PLD

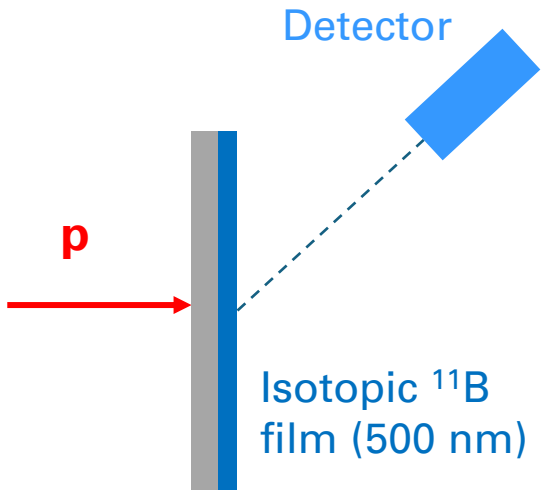
Boron films

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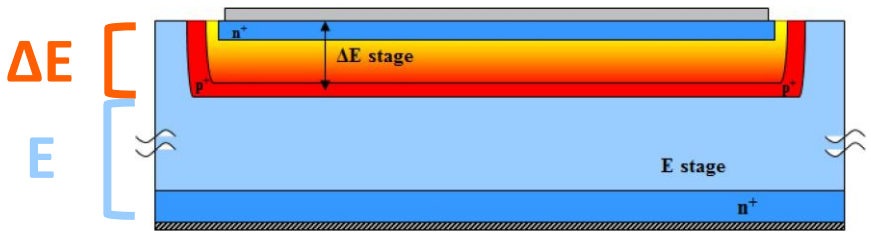
Dellasega D. et al., accepted in Appl. Sur. Sci., 2026

ns-PLD: boron thin films for cross-section studies

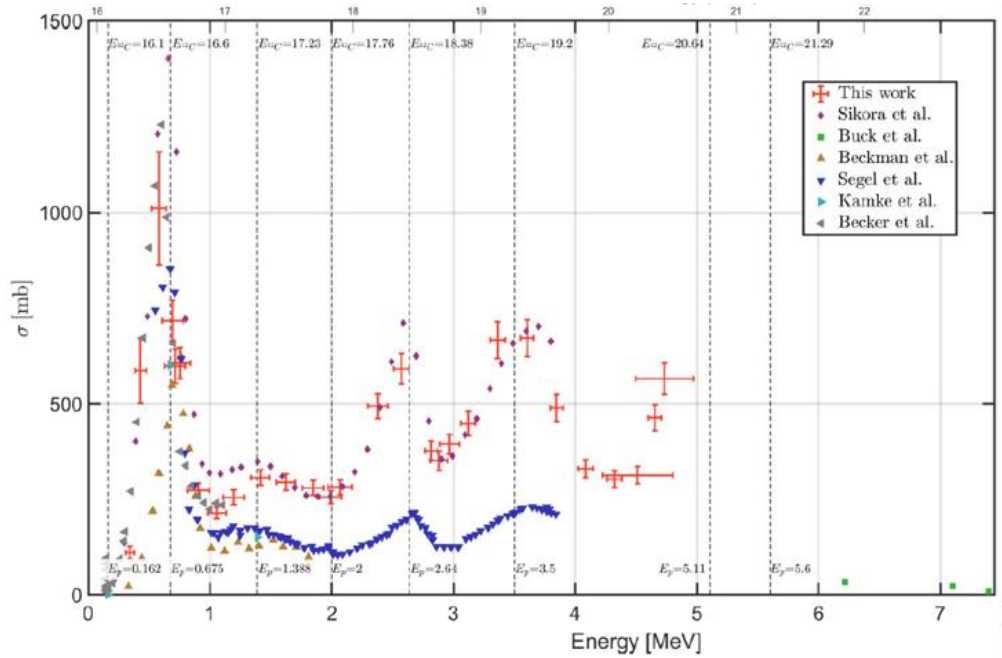
Radiation metrology group @ PoliMi

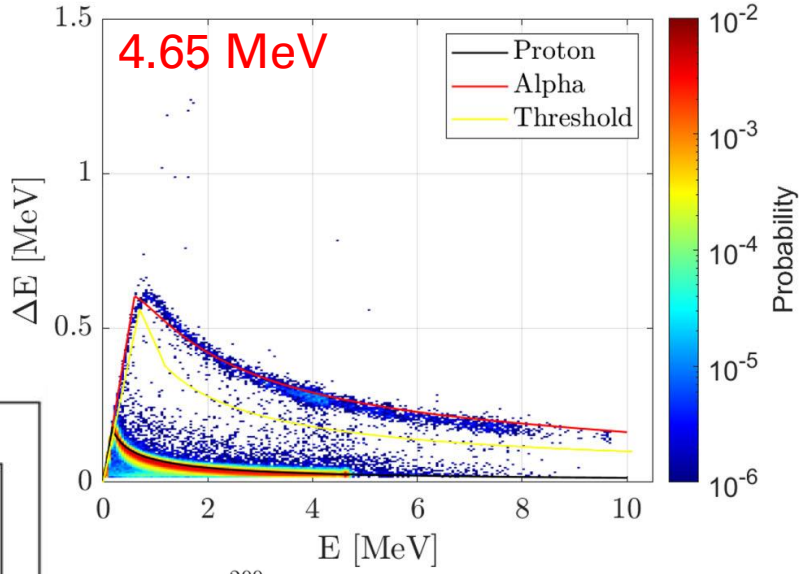


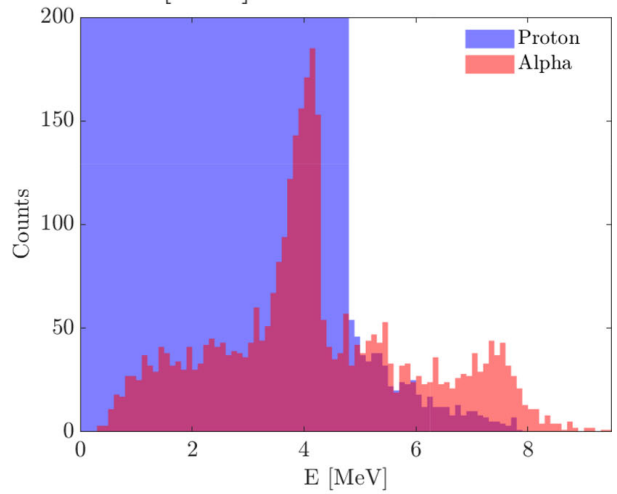
Silicon **telescope detector**



Mazzucconi D. et al., Physica Medica 89, 2021







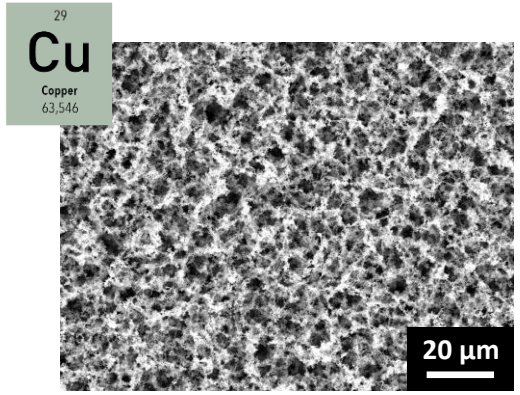
Target properties define **accuracy**

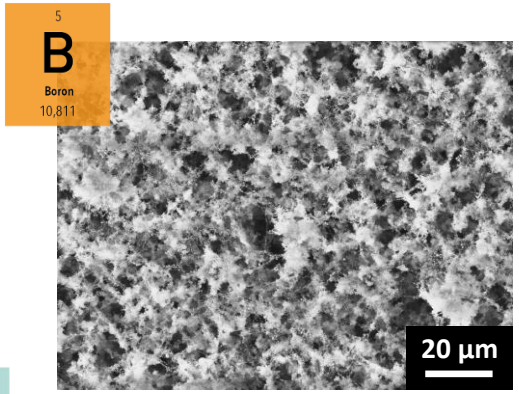
Mazzucconi D. et al., Eur. Phys. J. A, 2025

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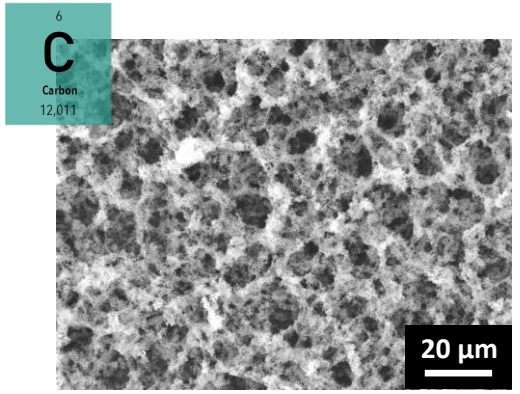
Boron films

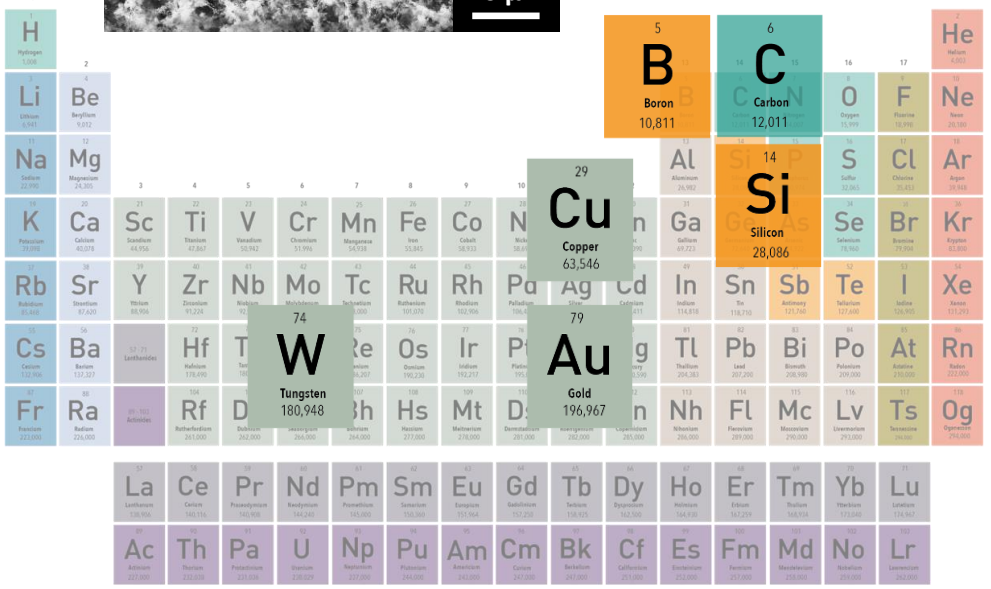
Not only boron: fs-PLD versatility

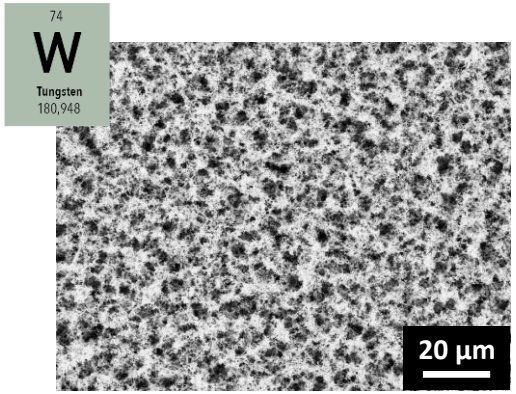


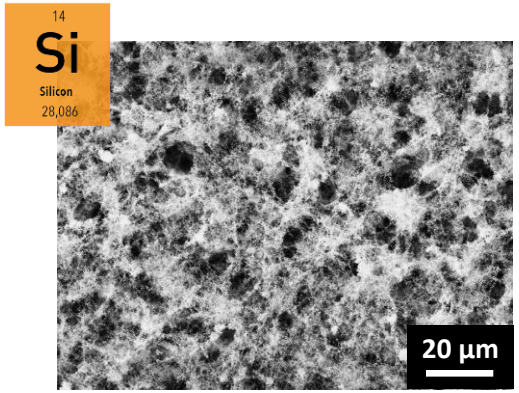


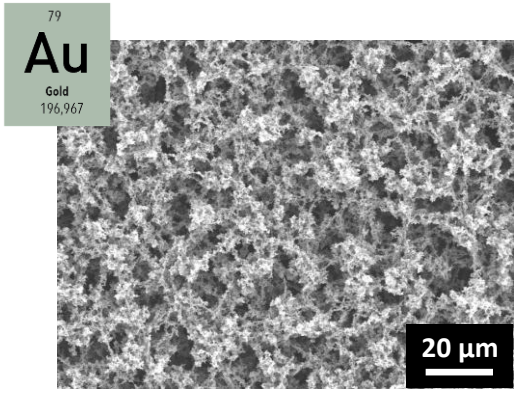
Nanofoam morphology









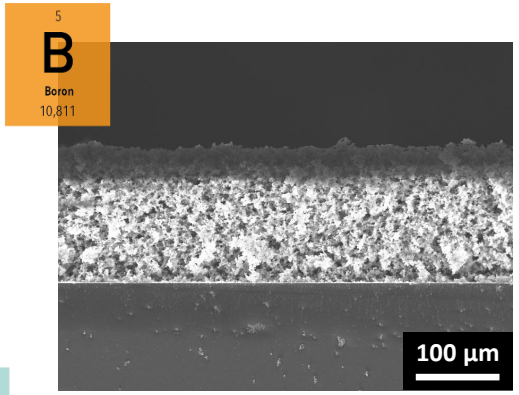


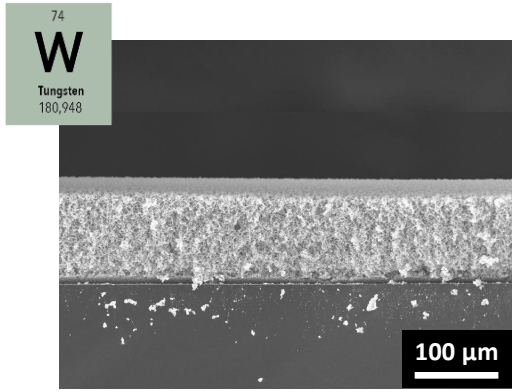
Same **ablation fluence** $\sim 0.1\ \mathrm{J/cm^2}$

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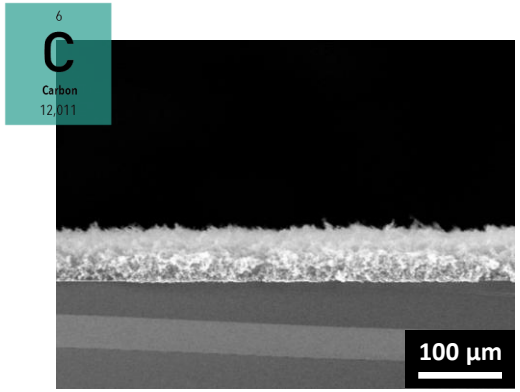
fs-PLD nanofoams

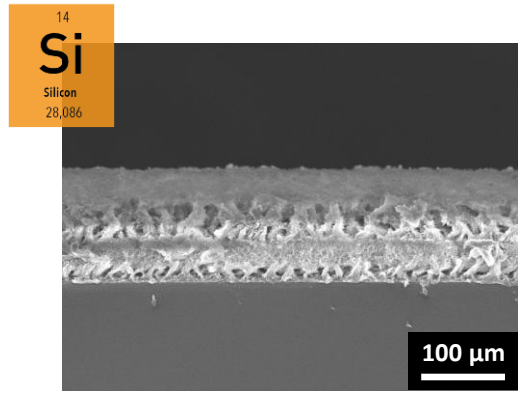
Not only boron: fs-PLD versatility

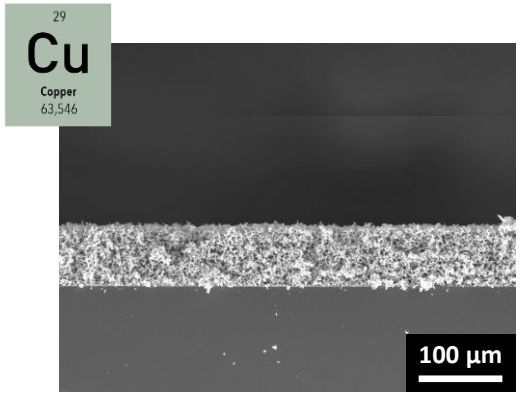


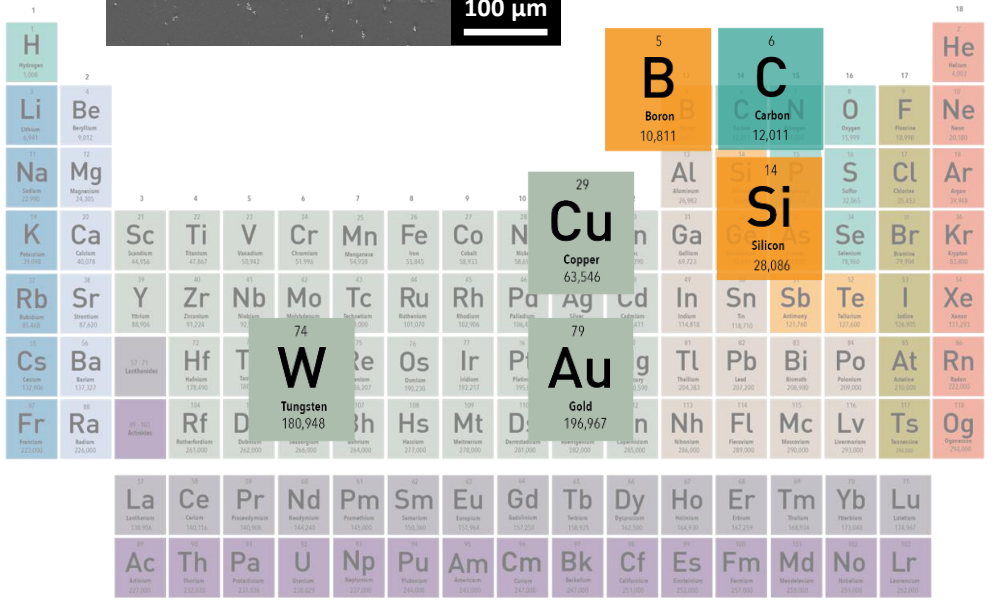


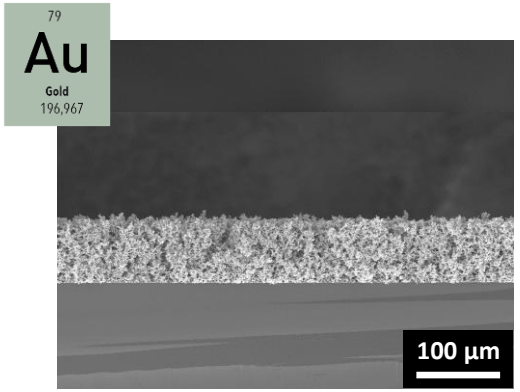
Nanofoam morphology











Same **ablation fluence** $\sim 0.1\ \mathrm{J/cm^2}$

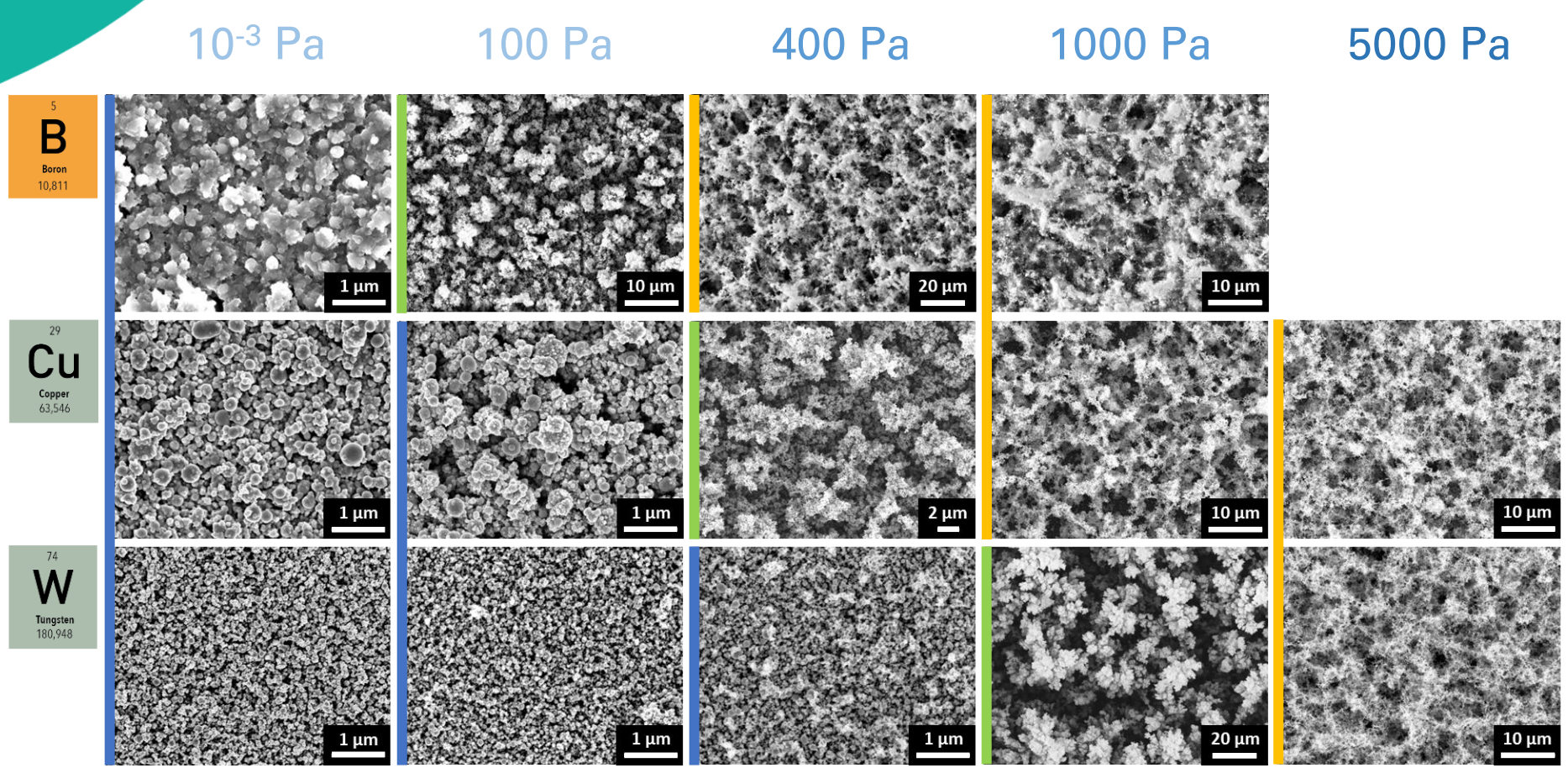
Exceeding **100 µm** thickness

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fs-PLD nanofoams

Beyond “just” nanofoams

Argon gas **pressure**



Same morphology evolution

Different pressure thresholds

Nanoparticle-assembled “compact” film → **Tree-like** nanostructured film → Web-like **nanofoam**

fs-PLD nanofoams

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Orecchia D. et al., Small Structures 5, 2024

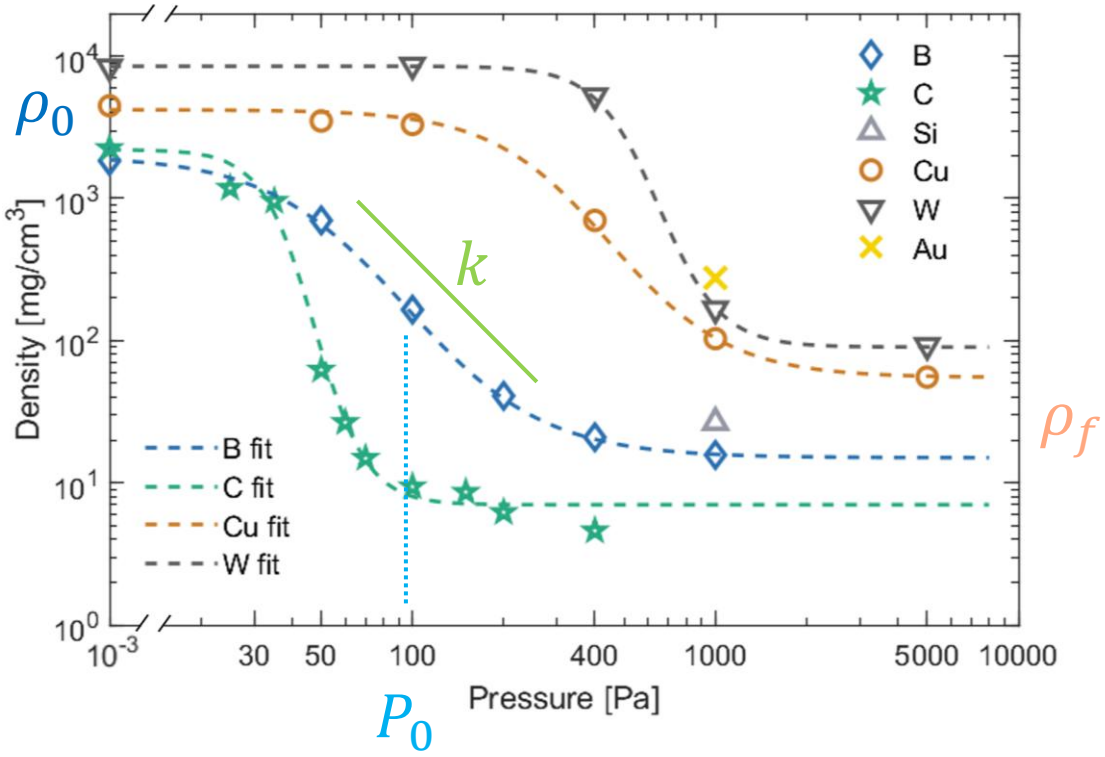
Average density and gas pressure

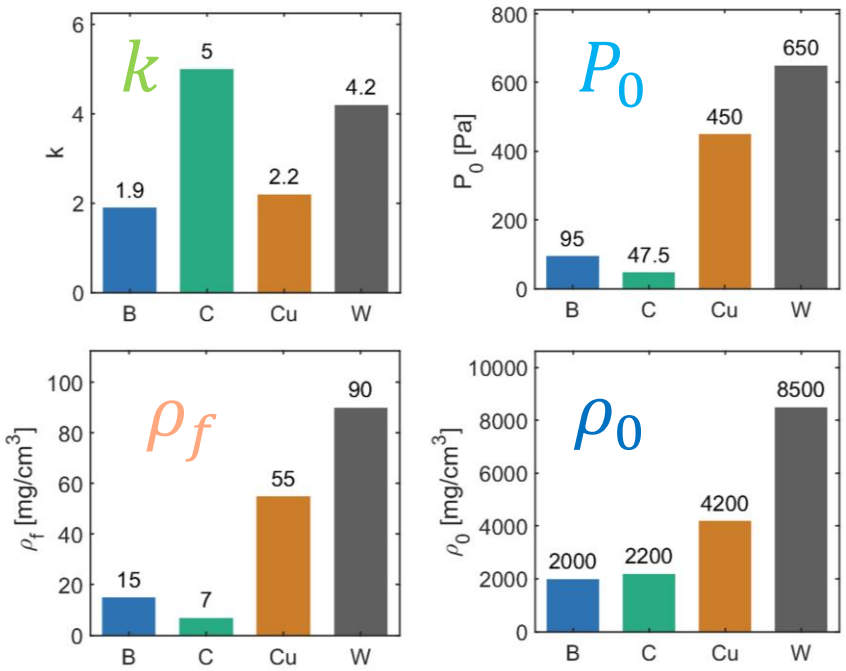
$$\rho(P) = \rho_0 \left(\frac{\rho_f}{\rho_0}\right)^{\left[\frac{P^k}{P^k + P_0^k}\right]}$$

$$\dot{v} = -\gamma v \qquad \gamma \propto \frac{P}{R\rho v_t}$$

Relative **slowing efficiency** of the background gas

Dimension, **energetics** and **density** of ablated nanoparticles





Nanofoam **average density** and **morphology**

Orecchia D. et al., Small Structures 5, 2024

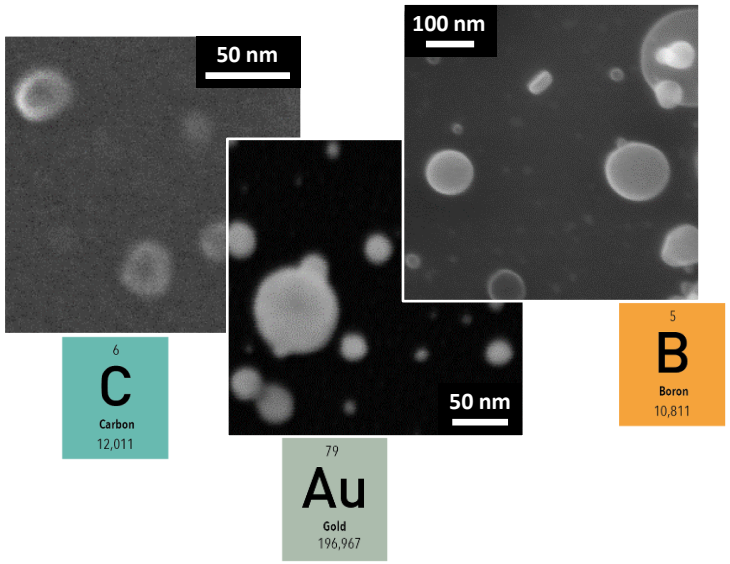
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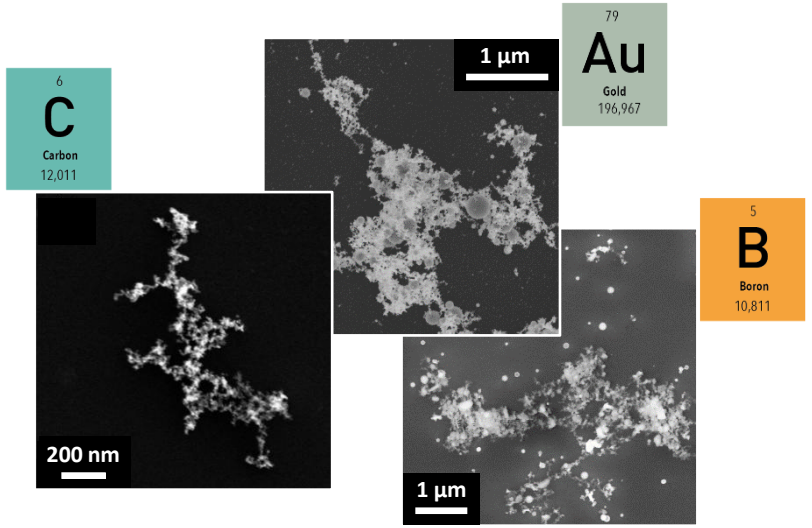
fs-PLD nanofoams

Nanofoam growth mechanism

1

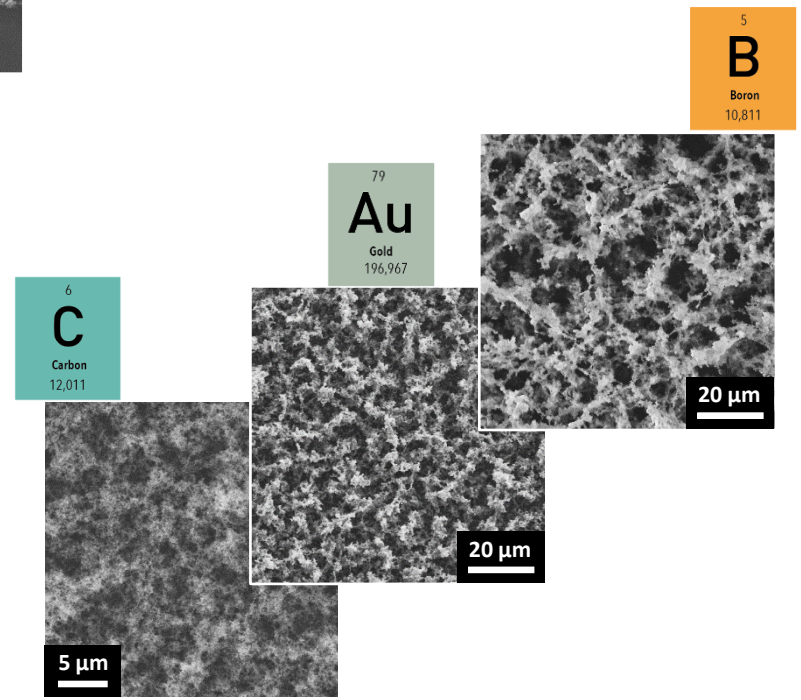
Nanoparticle production





2

In-flight interaction and **fractal aggregate** formation



3

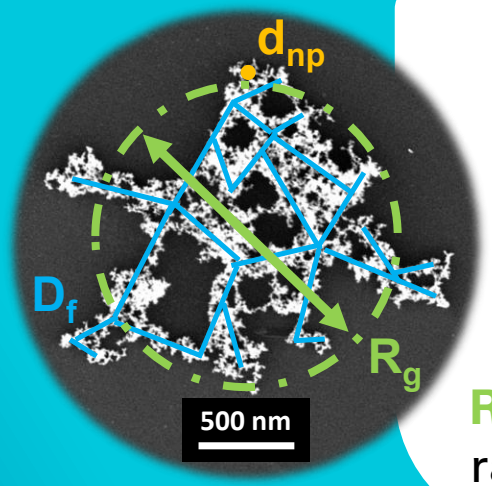
Deposition on the substrate and foam growth

Maffini A. et al., Phys. Rev. Mat. 3.8, 2019

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Simulated nanofoams

Simulation of nanofoam aggregation



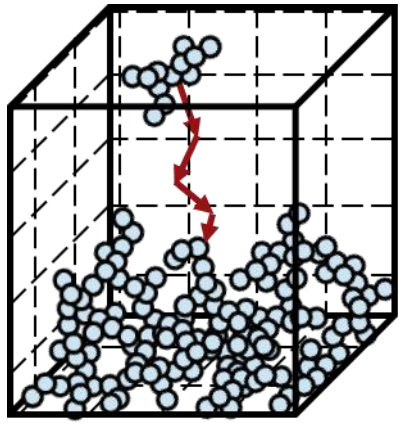
d_{np} nano-particle size

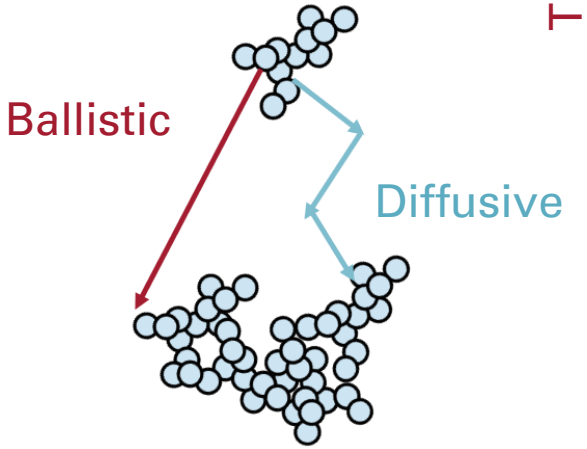
D_f fractal dimension

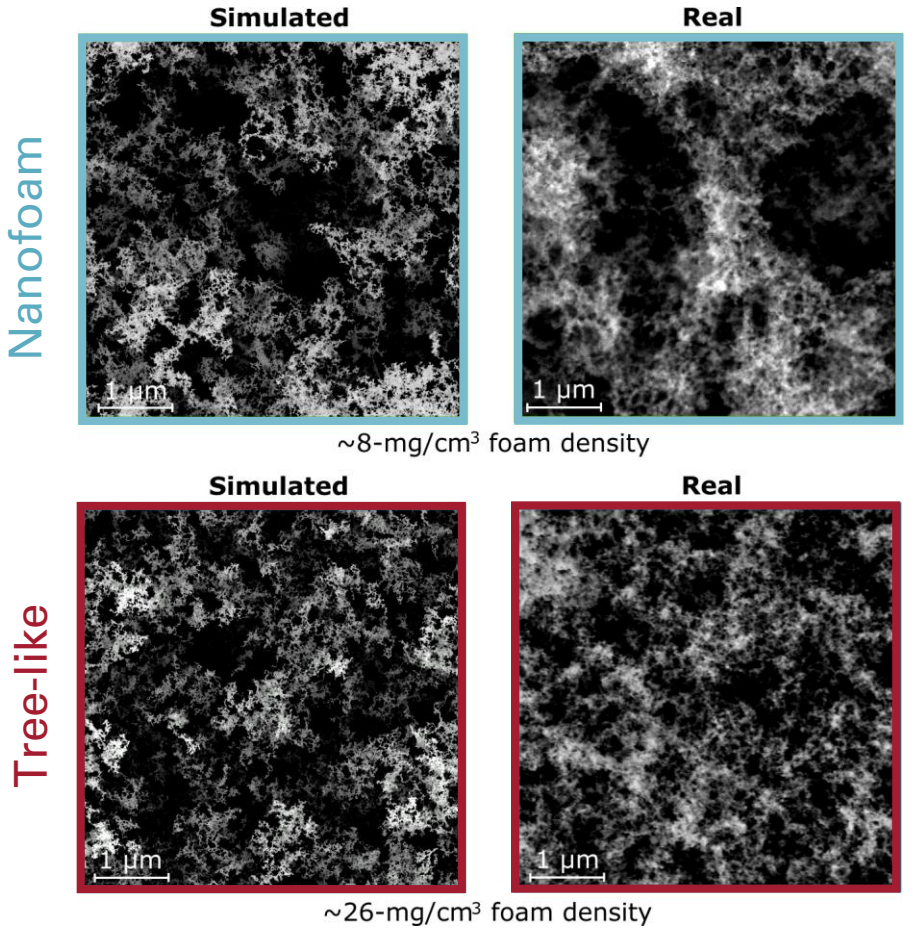
R_g gyration radius

$$\rho_{th} \cong k\rho_{np}\left(\frac{d_{np}}{2R_g}\right)^{3-D_f}$$

Cluster-cluster aggregation model







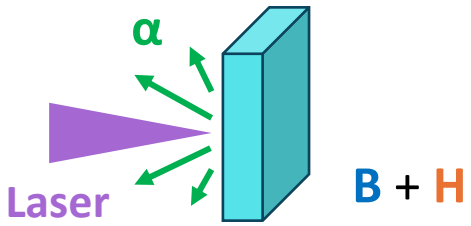
PIC simulations with **realistic morphology**

Simulated nanofoams

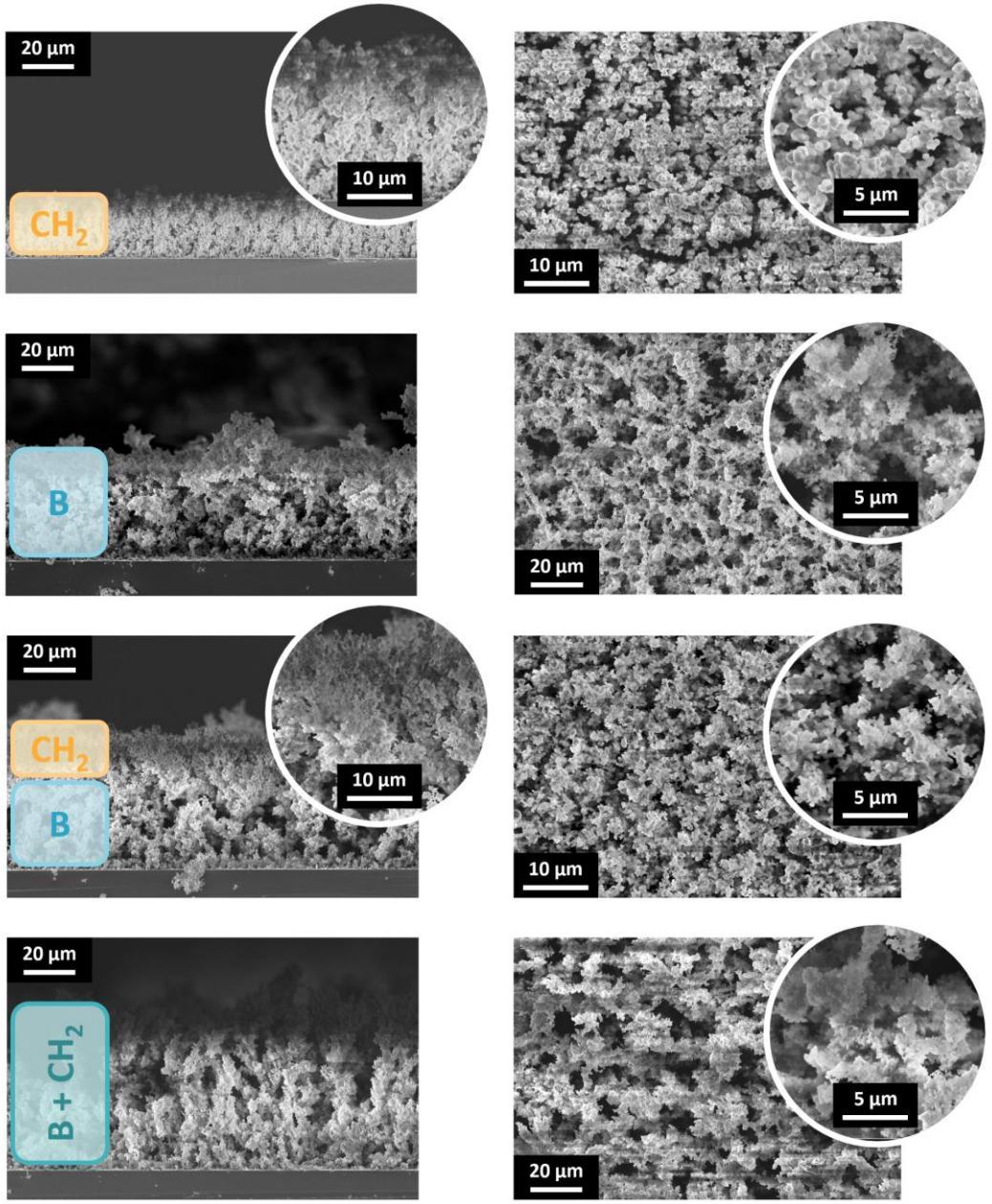
Maffini A. et al., Plasma Phys. Contr. Fusion 68, 2026

Boron nanofoams for proton-boron fusion

$$p + {}^{11}B \rightarrow 3\alpha + E$$



Hydrogen-enriched boron nanofoams



- Thickness: 20–100 µm
- Density: 50–120 mg/cm^3
- BN & PP substrates

fs-PLD **codeposition** through a **boron/HDPE** target

H/B ratio of **1.5**

20% C, 10% O

Nanofoams in p-11B fusion

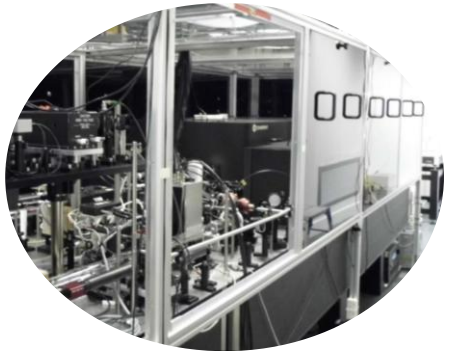
Maffini A. et al., Plasma Phys. Contr. Fusion 68, 2026

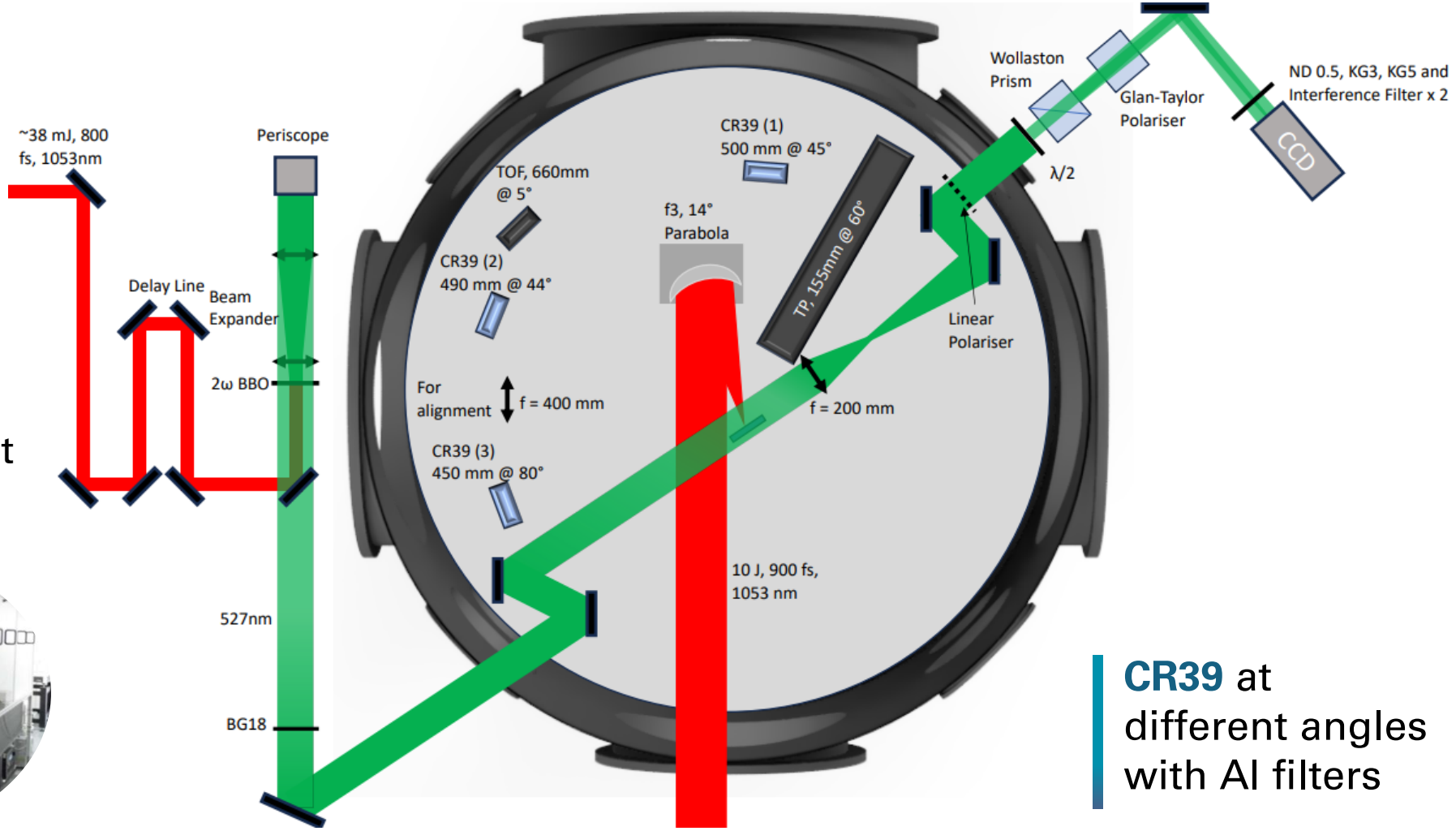
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Proton-boron experimental campaign

TARANIS

- **10 J**
- **800 fs**
- $\lambda = 1053$ **nm**
- 5.5 μm spot size
- 10^{19} **W/cm²**
- 5×10^{-7} contrast





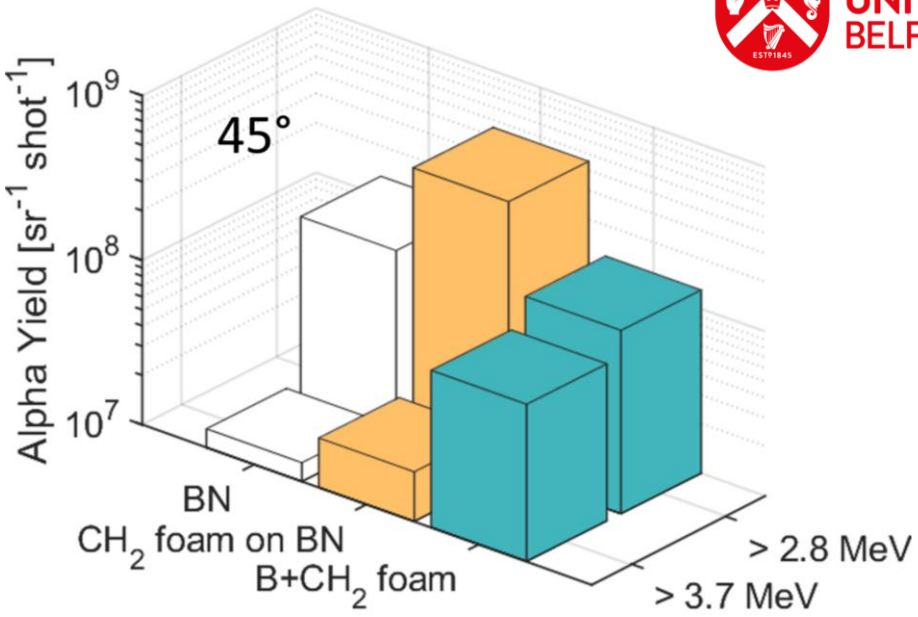
CR39 at different angles with Al filters

Molloy D. P. et al., *Phys. Rev. Res.* 7, 2025

Nanofoams in p-11B fusion

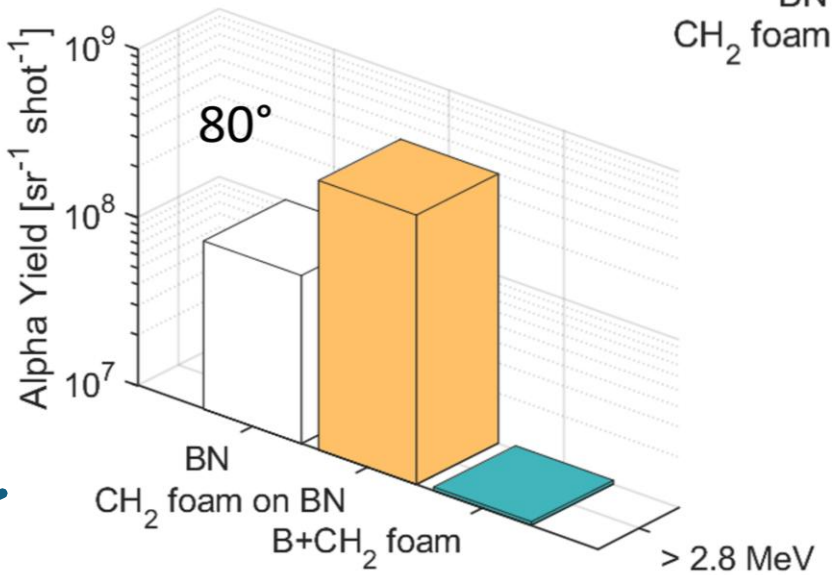
Experimental campaign results

In-foam proton-boron fusion reactions



Substantial alpha yield **enhancement**

Shielding effect



New experiment planned at ELI-BL in November

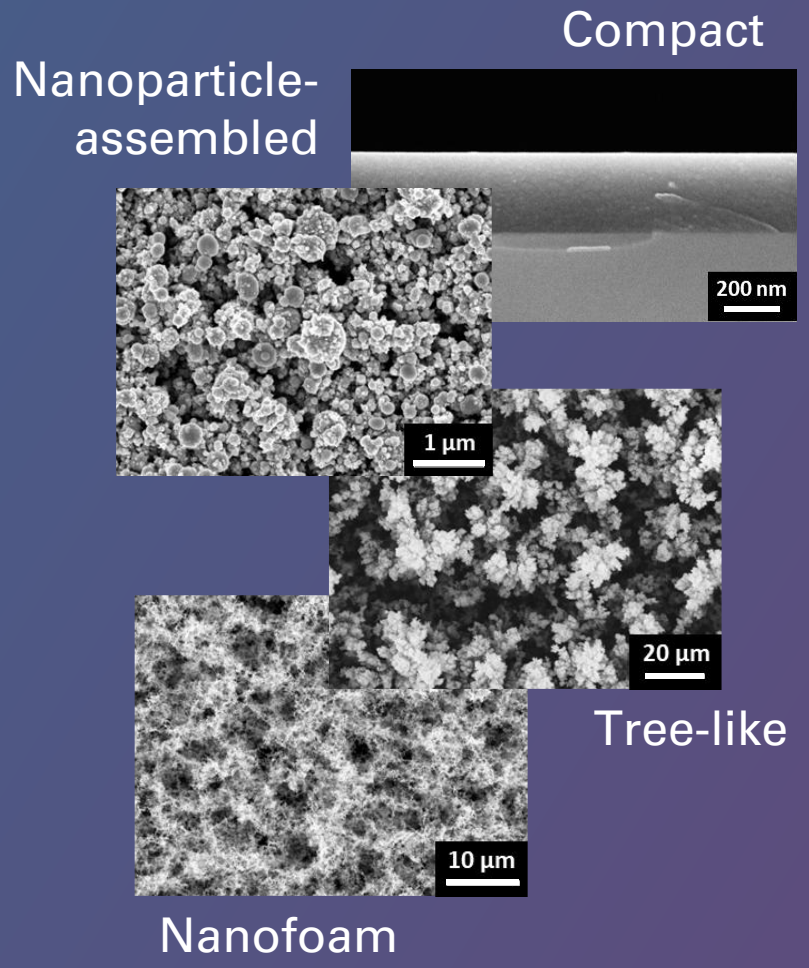
- 25 fs, 10 J, 10^{21} W/cm^2
- Double Plasma Mirror

Molloy D. P. et al., Phys. Rev. Res. 7, 2025

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Nanofoams in p-11B fusion

Conclusions & perspectives





Explore other elements and **compounds**

ns-PLD and fs-PLD are **complementary** and **versatile** techniques

Ammonia borane nanofoams

Foam targets & **high repetition rate** operation

Material **properties**

Application **requirements**

HiPER+ EUROPEAN LASER FUSION ENERGY

EUROfusion

eli

ENEA

P4P Plasma Stopping Power

MarvelFusion

Lawrence Livermore National Laboratory

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Conclusions

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Thank you for your attention!