ADVANCES IN PRODUCTION AND CHARACTERIZATION OF NEAR CRITICAL CARBON FOAM TARGETS

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ERC-2014-CoG No. 647554

INTRODUCTION

- Advances in *production, characterization and simulation* of of **ultra-low density carbon → CARBON FOAM**
- **@ Micro and Nano-structured Materials Laboratory (Nanolab)** (Politecnico di Milano)
- Exploited as a **near critical coating → enhanced laser-driven ion acceleration**

CRITICAL DENSITY

$$n_c = \gamma \frac{m_e \omega^2}{4\pi e}$$

$$\gamma = \sqrt{0.723\, I[10^{18}\, W/cm^3]\, \lambda^2[\mu m^2] + 1}$$

Relativistc transparency

$I = 10^{20}\, W/cm^3$, $\lambda = 532$ nm } $\gamma \approx 4.6$

C fully ionized (γ=1) $n_c \approx 5.7\ g/cm^3$

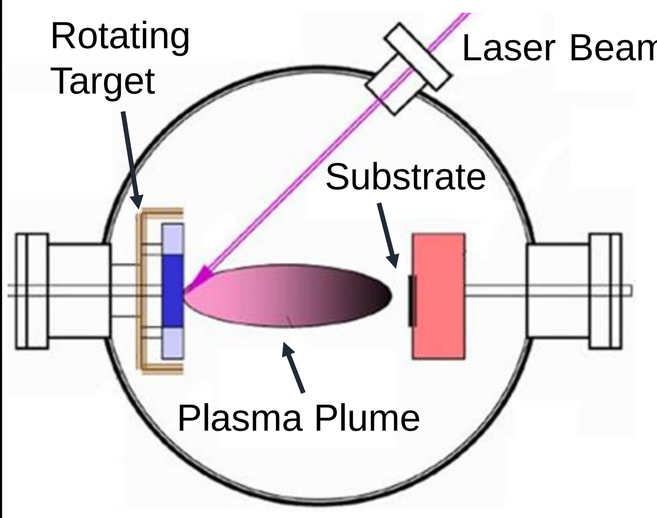
$n<n_c$ Undercritical regime ⇒ Electromagnetica wave **propagation**

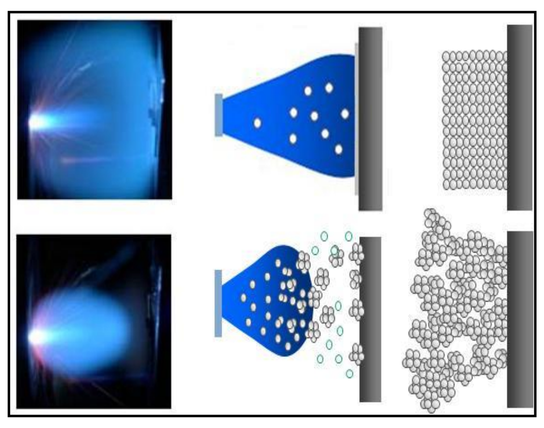
$n>n_c$ Overcritical regime ⇒ Wave **damping**, high reflection

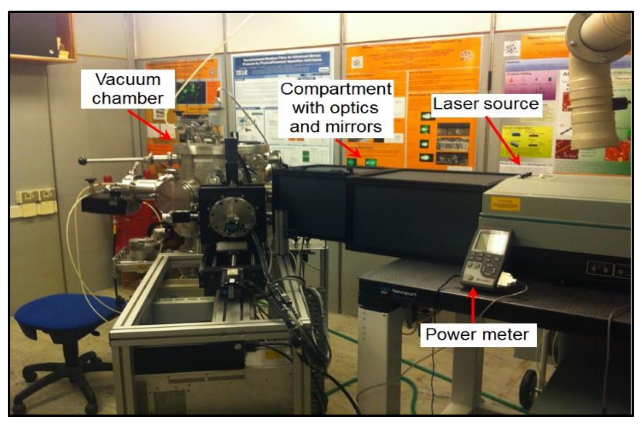
$n \sim n_c$ Near critical regime ⇒ **High** laser-plasma **coupling**

PRODUCTION

Pulsed Laser Deposition (PLD) of nanostructured targets



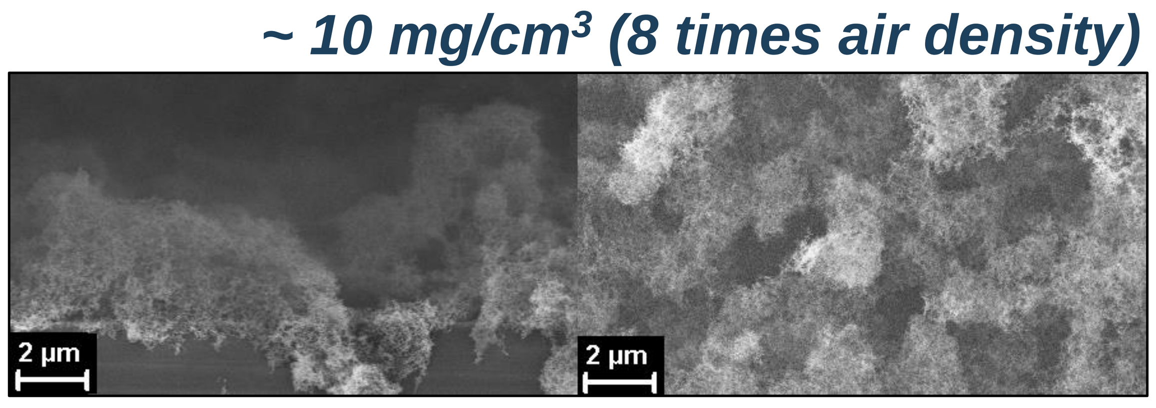




Deposition of different morphologies:

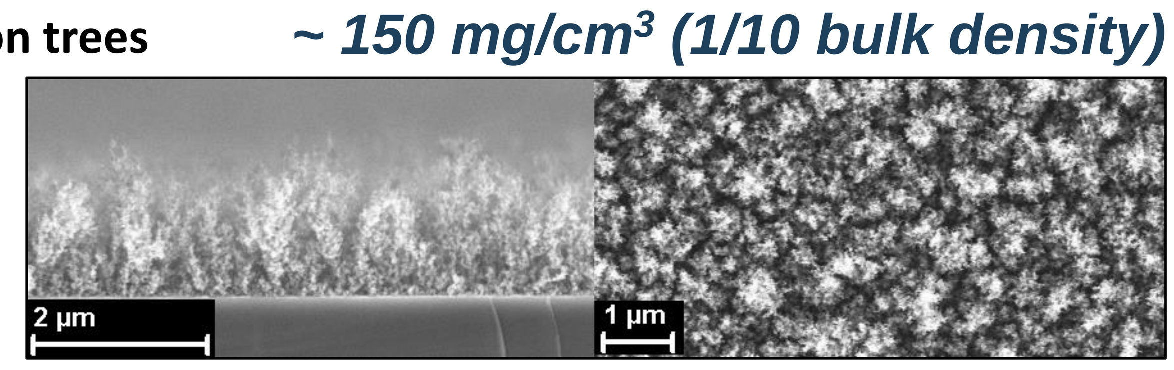
- **Low density Carbon foam** — ***~ 10 mg/cm³ (8 times air density)***

  Buffer Gas: Ar
  λ = 532 nm
  E = 130 mJ
  P = 500 Pa
  Gas flow = 1.4 sccm
  Substrate-Target distance = 4.5 cm



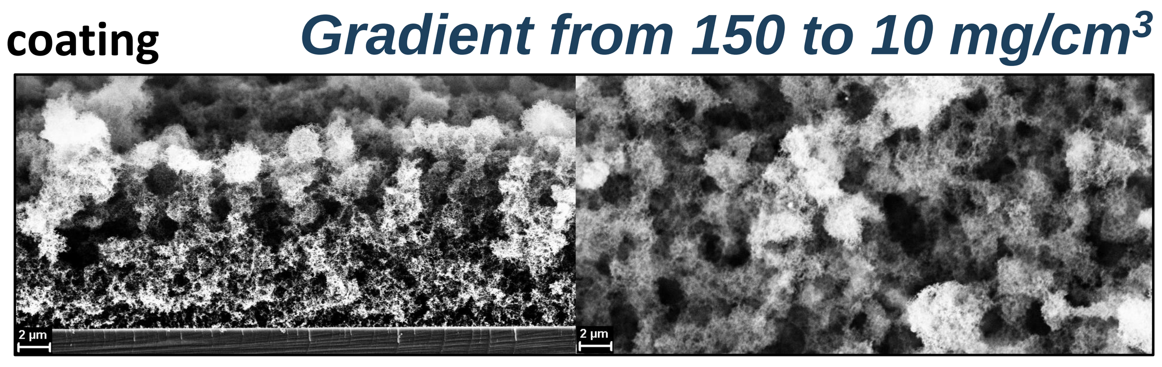
- **Intermediate density Carbon trees** — ***~ 150 mg/cm³ (1/10 bulk density)***

  Buffer Gas: Ar
  λ = 532 nm
  E = 130 mJ
  P = 50 Pa
  Gas flow = 80 sccm
  Substrate-Target distance = 4.5 cm



- **Functionally graded Carbon coating** — ***Gradient from 150 to 10 mg/cm³***

  Buffer Gas: Ar
  λ = 532 nm
  E = 150 mJ
  P = 100->700 Pa (linear)
  Gas flow = 0 sccm
  Substrate-Target distance = 4.5 cm

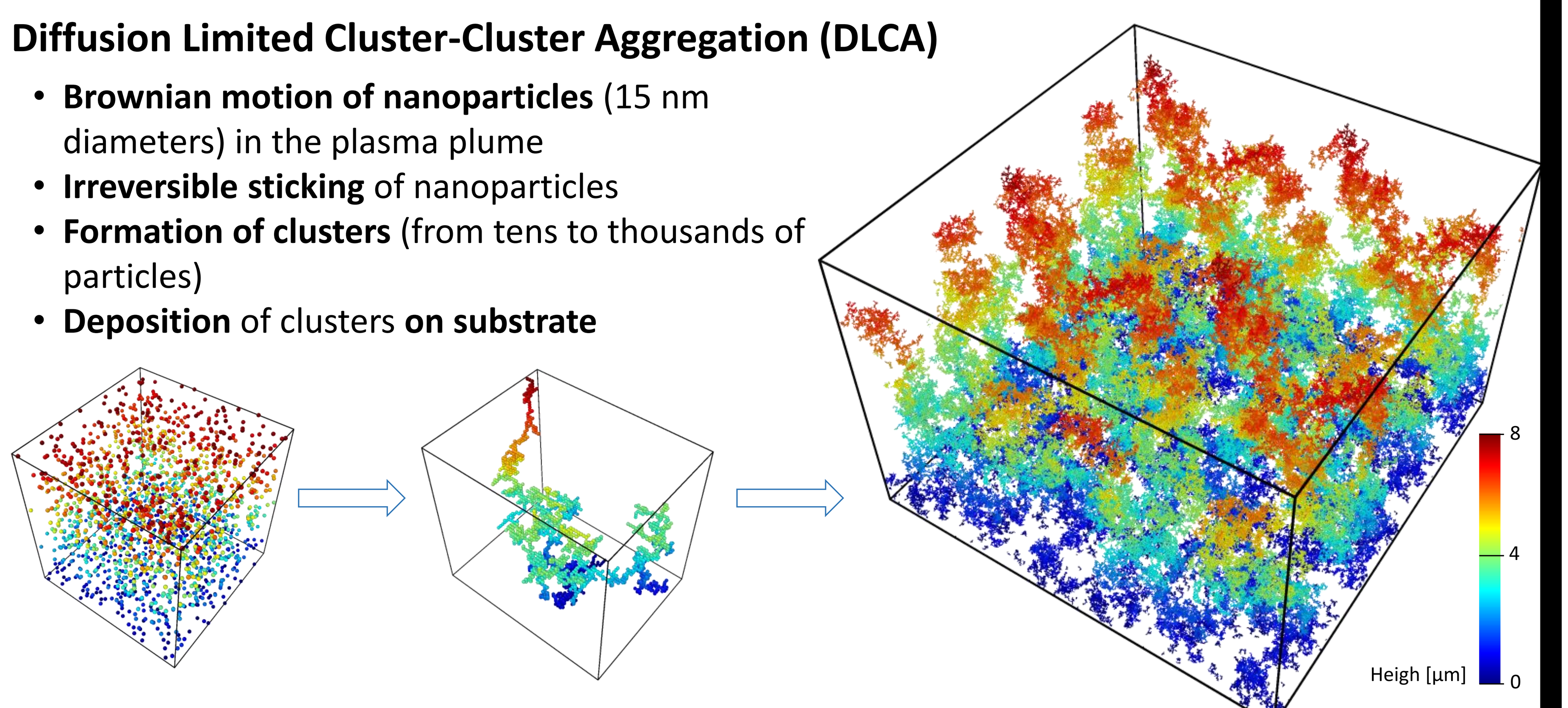


Zani, A., et al. "Ultra-low density carbon foams produced by pulsed laser deposition." Carbon 56 (2013): 358-365.

FOAM SIMULATION

Diffusion Limited Cluster-Cluster Aggregation (DLCA)

- **Brownian motion of nanoparticles** (15 nm diameters) in the plasma plume
- **Irreversible sticking** of nanoparticles
- **Formation of clusters** (from tens to thousands of particles)
- **Deposition** of clusters **on substrate**

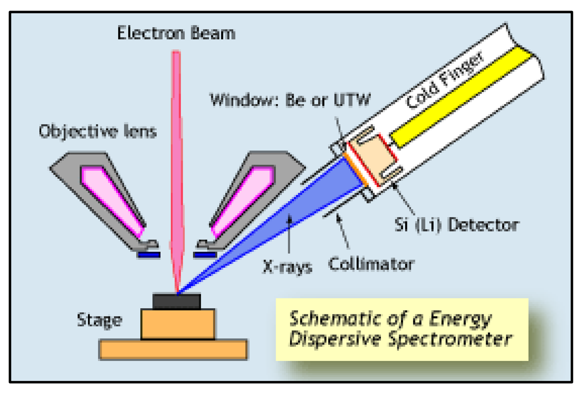


CHARACTERIZATION

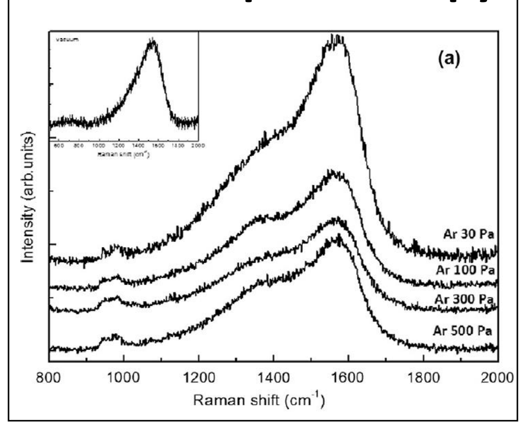
Density measurement

$\rho = \tau\, t$ ⇒ *Thickness* with SEM

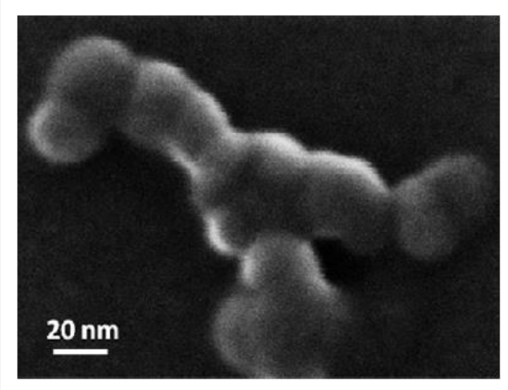
Areal Density with new technique based on Energy Dispersive X-ray Spectroscopy (EDS)



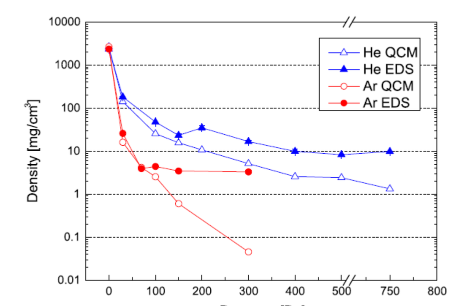
Raman Spectroscopy



SEM & HR-TEM



Semiempirical model → Density-pressure measures

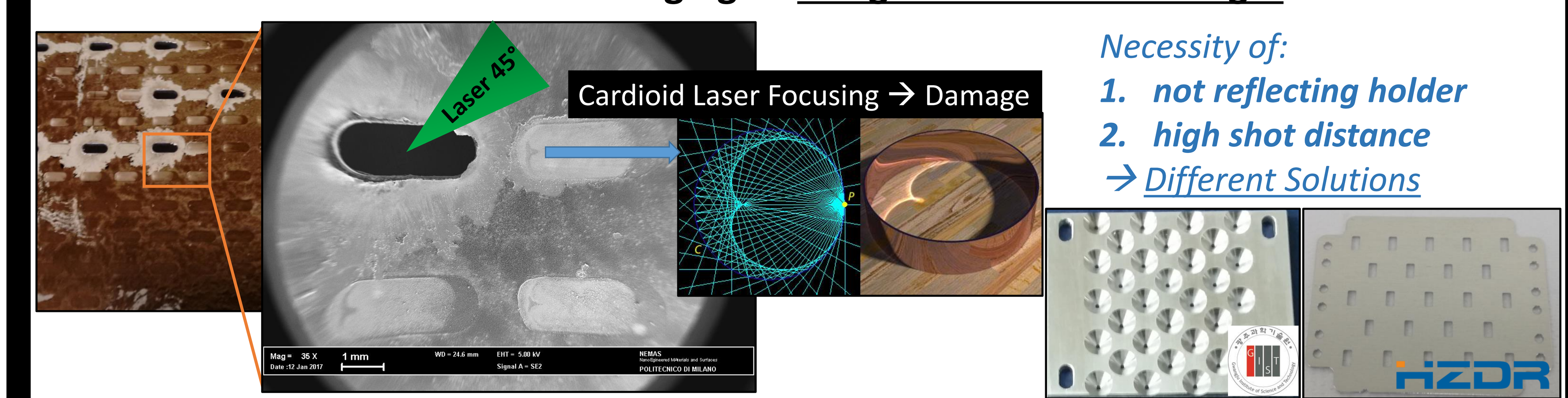


A ***new Theoretical Model*** *(solution of transport equation for electron) is under validation →* ***more reliable***

Prencipe, Irene, et al. "Energy dispersive x-ray spectroscopy for nanostructured thin film density evaluation." Science and Technology of Advanced Materials 16.2 (2015): 025007.

FOAM BASED TARGET

- The C foam che be **deposited on every kind of substrate**
- The foam suffer from **laser damaging → designed foam based target**

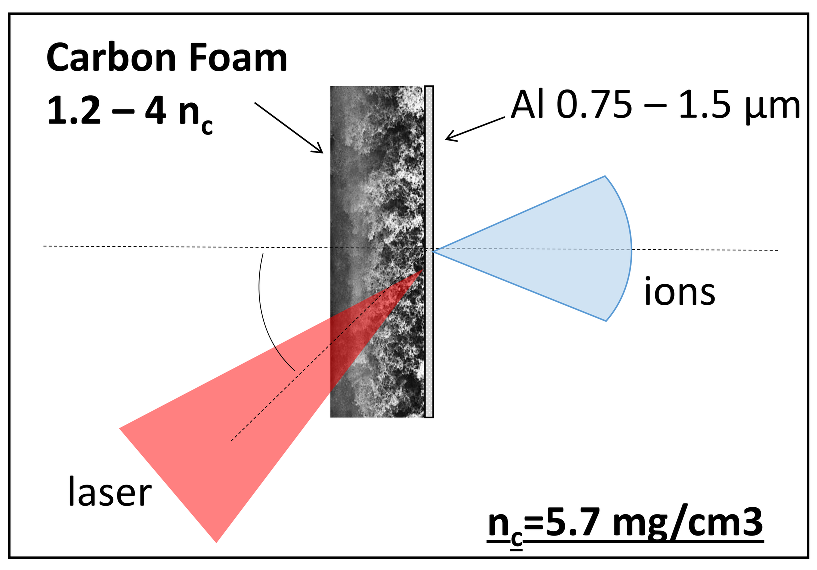


Necessity of:

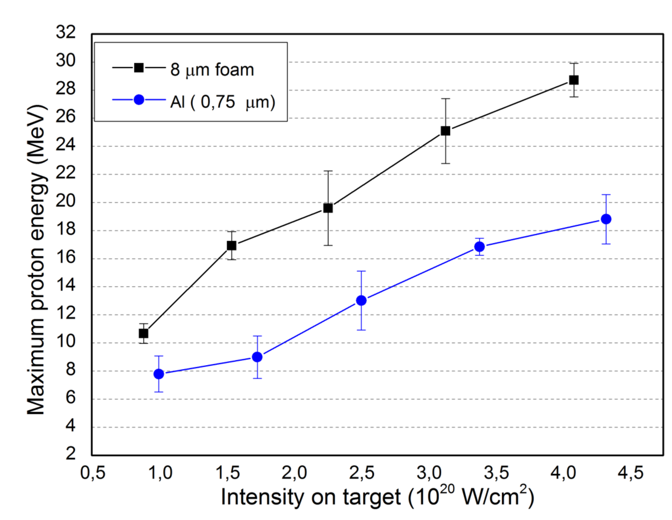
1. ***not reflecting holder***
2. ***high shot distance***

→ Different Solutions

LASER-DRIVEN ION ACCELERATION RESULTS



+ 30% enhancement!



Ion acceleration experiments:
- Performed at **SLIC** (France) in 2014
- Performed at **GIST** (Rep. of Korea) in 2015-2016
- Performed at **HZDR** (Germany) in 2017

Passoni, Matteo, et al. "Energetic ions at moderate laser intensities using foam-based multi-layered targets." Plasma Physics and Controlled Fusion 56.4 (2014): 045001.
Prencipe, I., et al. "Development of foam-based layered targets for laser-driven ion beam production." Plasma Physics and Controlled Fusion 58.3 (2016): 034019.
Passoni, M., et al. "Toward high-energy laser-driven ion beams: Nanostructured double-layer targets." Physical Review Accelerators and Beams 19.6 (2016): 061301

CONCLUSION AND FUTURE PERSPECTIVE

We are able to:
- Produce C coating with **tunable ultra-low density** (10-150 mg/cm³) on every kind of substrate
- Produce **functionally graded coatings**
- **Simulate the material** at the mesoscale (>10 nm)
- **Measure the mean density** with novel method based on EDS
- Design the foam based target for laser-driven **enhaced ion acceleration**

In the future we will be able to:
- Produce C coatings with **femtoseconds laser PLD** and **High Power Impulse Magnetron Sputtering**
- **Increse the control** on the C foam parameters (*lower density, designed gradients*)
- Use laser-driven ion for **applied science** (*ion beam analysis, neutron imaging, ion implantation, radiation damaging*)